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Environmental Assessment of a Crude-Oil Heater Using Staged Air Lances for NOx Reduction Volume 1. Technical Results

Acurex Corp., Mountain View, CA

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ENVIRONMENTAL ASSESSMENT OF A CRUDE-OIL HEATER USING STAGED AIR LANCES FOR NO_x REDUCTION

Volume I
Technical Results

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16. ABSTRACT This volume of the report gives emission results from field tests of a crude-oil process heater burning a combination of oil and refinery gas. The heater had been modified by adding a system for injecting secondary air to reduce NOx emissions. One test was conducted with the staged air system (low NOx), and the other, without (baseline). Tests included continuous monitoring of flue gas emissions and source assessment sampling system (SASS) sampling of the flue gas with subsequent laboratory analysis of the samples utilizing gas chromatography (GC), infrared spectrometry (IR), gas chromatography/mass spectroscopy (GC/MS), and low resolution mass spectrometry (SSMS) for trace metals. Flue gas concentrations of NOx were reduced 30 percent (from 83 to 56 ng/J) with the staged air system. Total organic emissions dropped from 17.1 to 3.4 mg/dscm from the baseline to the low-NOx test (due primarily to a reduction in the C sub 1 to C sub 6 boiling point range compounds which constituted most of the organic emissions). GC/MS analysis identified 11 semivolatile priority pollutant compounds in both tests, most of them present in higher concentrations during the baseline test. LRMS analysis suggested the presence of eight compound categories in the organic emissions during the baseline test and four in the low-NOx test.

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a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Assessments	Pollution Control	13B 14B
Nitrogen Oxides	Stationary Sources	07B
Crude Oil	Staged Combustion	11H, 08G
Gases	Refinery Gas	07D
Heating Equipment	Air Lances	13A
Lances	Environmental Assessment	13I 21B
Flue Gases		

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SECTION 1

INTRODUCTION

This report describes and presents results of environmental assessment tests performed for the Industrial Environmental Research Laboratory/Research Triangle Park (IERL/RTP) of the Environmental Protection Agency (EPA) under the Combustion Modification Environmental Assessment (CMEA) program, EPA Contract No. 68-02-3188. The CMEA started in 1976 with a 3-year study (NO_x EA), EPA Contract No. 68-02-2160, having the following four objectives:

- Determine multimedia environmental effects from stationary combustion sources and combustion modification technology
- Develop and document control application guidelines to minimize these effects
- Identify stationary source and combustion modification R&D priorities
- Disseminate program results to intended users

During the first year of the NO_x EA, data and methodologies for the environmental assessment were compiled. Furthermore, priorities for the schedule and level of effort for the various source/fuel/control combinations were identified. This effort revealed major data gaps, particularly for noncriteria pollutants (organic emissions and trace elements) for virtually all combinations of stationary combustion sources and combustion modification techniques. Consequently, seven environmental field test programs were

undertaken to fill these data gaps. The results of these tests are documented in seven individual reports (references 1-1 through 1-7) and in the final NO_x EA report summarizing the entire 3-year effort (reference 1-8).

The current CMEA program has as its major objective the continuation of multimedia environmental field tests initiated in the original NO_x EA program. These tests, using standardized Level 1 sampling and analytical procedures (reference 1-9) are aimed at filling the remaining data gaps and addressing the following priority needs:

Advanced NO_x controls

Alternate fuels

Secondary sources

EPA program data needs

-- Residential oil combustion

-- Wood firing in residential, commercial, and industrial sources

-- High interest emissions determination (organics, radionuclides, candidate hazardous air pollutant species, etc.)

Nonsteady-state operations

Advanced forms of combustion modifications have been developed in recent years as a means of reducing NO_x emissions without adverse consequences, such as capacity loss caused by derating the unit. Staged combustion using air injection lances is one form of combustion modification that is relatively easy to retrofit to industrial-sized combustion equipment since it requires only minor hardware modification.

A refinery crude oil heater, using staged combustion by means of air injection lances (reference 1-10), was selected for environmental tests under the CMEA program. The objective of the tests was to quantify air emissions from the heater operating in its normal state and compare these with emissions

from the heater in the low-NO_x configuration while using the air lances. The data presented in this report quantify stack emissions and identify pollutants of concern using results from standard sampling and analytical procedures.

Table 1-1 lists all tests performed to date in the CMEA effort and outlines the source, fuel, combustion modifications, and level of sampling and analysis in each case. Results of these test programs are discussed in separate reports available through EPA.

Table 1-1. Completed Tests During the Current Program

Source	Description	Test Points Unit Operation	Sampling Protocol	Test Collaborator
Spark ignited natural gas-fired reciprocating internal combustion engine	Large bore, 6-cylinder, opposed piston, 186 kW (250 Bhp)/cyl, 900 rpm, Model 38TDS8-1/8	-- Baseline (pre-NSPS) -- Increased air-fuel ratio aimed at meeting proposed NSPS of 700 ppm corrected to 15 percent O_2 and standard atmospheric conditions	Engine exhaust: -- SASS -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Lube oil	Fairbanks Morse Division of Colt Industries
Compression ignition diesel-fired reciprocating internal combustion engine	Large bore, 6-cylinder opposed piston, 261-kW (350 Bhp)/cyl, 900-rpm, Model 38TDD8-1/8	-- Baseline (pre-NSPS) -- Fuel injection retard aimed at meeting proposed NSPS of 600 ppm corrected to 15 percent O_2 and standard atmospheric conditions	Engine exhaust: -- SASS -- Method 8 -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Lube oil	Fairbanks Morse Division of Colt Industries
Low-NO_x residential condensing heating system furnished by Karlsons Blueburner Systems Ltd. of Canada	Residential hot water heater equipped with M.A.N. low-NO_x burner, 0.55 ml/s (0.5 gal/hr) firing capacity, condensing flue gas	Low-NO_x burner design by M.A.N.	Furnace exhaust: -- SASS -- Method 8 -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Waste water	New test
Rocketdyne/EPA low-NO_x residential forced warm air furnace	Residential warm air furnace with modified high pressure burner and firebox, 0.83 ml/s (0.75 gal/hr) firing capacity	Low-NO_x burner design and integrated furnace system	Furnace exhaust: -- SASS -- Method 8 -- Controlled condensation -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel	New test

Table 1-1. Continued

Source	Description	Test Points Unit Operation	Sampling Protocol	Test Collaborator
Pulverized coal-fired utility boiler, Conesville station	400-MW tangentially fired; new NSPS design aimed at meeting 301 ng/J NO_x limit	ESP inlet and outlet, one test	ESP inlet and outlet: -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2 Coal Bottom ash ESP ash	Exxon Research and Engineering (ER&E) conducting corrosion tests
Nova Scotia Technical College industrial boiler	1.14 kg/s steam (9,000 lb/hr) firetube fired with a mixture of coal-oil-water (COW)	-- Baseline (COW) -- Controlled SO_2 emissions with limestone injection	Boiler outlet: -- SASS -- Method 5 -- Method 8 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, CO_2, CO, NO Fuel	Envirocon performed particulate and sulfur emission tests
Adelphi University industrial boiler	1.89 kg/s steam (15,000 lb/hr) hot water firetube fired with a mixture of coal-oil-water (COW)	-- Baseline (COW) -- Controlled SO_2 emissions with Na_2CO_3 injection	Boiler outlet: -- SASS -- Method 5 -- Method 8 -- Controlled condensation -- Gas Sample (C_1 - C_6 HC) -- Continuous O_2, CO_2, NO, CO Fuel	Adelphi University
Pittsburgh Energy Technology Center (PETC) industrial boiler	3.03 kg/s steam (24,000 lb/hr) watertube fired with a mixture of coal-oil (COM)	-- Baseline test only with COM	Boiler outlet: -- SASS -- Method 5 -- Controlled condensation -- Continuous O_2, CO_2, NO, TUHC, CO -- N_2O grab sample Fuel	PETC and General Electric (GE)

Table 1-1. Continued

Source	Description	Test Points Unit Operation	Sampling Protocol	Test Collaborator
TOSCO Refinery vertical crude oil heater	2.54 Ml/day (16,000 bbl/day) natural draft process heater burning oil/refinery gas	-- Baseline -- Staged combustion using air injection lances	Heater outlet: -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, NO, CO, CO_2, HC -- N_2O, grab sample Fuel oil Refinery gas	KVB coordinating the staged combustion operation and continuous emission monitoring
Mohawk-Getty Oil industrial boiler	8.21 kg/s steam (65,000 lb/hr) watertube burning mixture of refinery gas and residual oil	-- Baseline -- Ammonia injection using the noncatalytic Thermal DeNO$_x$ process	Economizer outlet: -- SASS -- Method 5, 17 -- Controlled condensation -- Gas Sample (C_1 - C_6 HC) -- Ammonia emissions -- N_2O grab sample -- Continuous O_2, NO, CO, CO_2 Fuels (refinery gas and residual oil)	New test
Industrial boiler	2.52 kg/s steam (20,000 lb/hr) watertube burning woodwaste	-- Baseline (dry wood) -- Green wood	Boiler outlet: -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, NO, CO Fuel Flyash	North Carolina Department of Natural Resources, EPA IERL-RTP
Industrial boiler	3.16 kg/s steam (29,000 lb/hr) firetube with refractory firebox burning woodwaste	-- Baseline (dry wood)	Outlet of cyclone particulate collector: -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, NO$_x$, CO Fuel Bottom ash	North Carolina Department of Natural Resources, EPA IERL-RTP

Table 1-1. Continued

Source	Description	Test Points Unit Operation	Sampling Protocol	Test Collaborator
Enhanced oil recovery steam generator	15 MW (50 million Btu/hr) steam generator burning crude oil equipped with MHI low-NO_x burner	-- Performance mapping -- Low NO_x operation	Steamer outlet: -- SASS -- Method 5 -- Method 8 -- Gas sample (C_1 - C_6 HC) Continuous O_2, NO_x, CO, CO_2 N_2O grab sample Fuel	Getty Oil Company, CE-Natco
Pittsburgh Energy Technology Center (PETC) industrial boiler	3.03 kg/s steam (24,000 lb/hr) watertube fired with a mixture of coal-water (CWM)	-- Baseline test only with CWM	Boiler outlet: -- SASS -- Method 5 -- Method 8 -- Gas sample (C_1 - C_6 HC) Continuous O_2, NO_x, CO, CO_2, TUHC N_2O grab sample Fuel Bottom ash Collector hopper ash	PETC and General Electric

Table 1-1. Concluded

Source	Description	Test Points Unit Operation	Sampling Protocol	Test Callaborator
Internal combustion engine -- nonselective NO_x catalyst	818 HP Waukesha engine equipped with DuPont NSER catalyst	-- Baseline	Catalyst inlet and outlet -- SASS -- NH_3 -- HCN -- Grab sample N_2O -- Continuous O_2, CO_2, NO_x TUHC fuel	Southern California Gas
Industrial boiler	180 kg/hr steam (400 lb/hr) stoker fired with a mixture of coal and waste plastic	-- Baseline (coal) -- Coal and plastic	Boiler outlet -- SASS -- VOST -- Method 5/8 -- HCl -- Continuous O_2, NO_x, CO, CO_2, TUHC -- N_2O grab sample Fuel Flyash Bottom ash Cyclone ash	Vermont Agency of Environmental Conservation
Industrial boiler	7.6 kg/s steam (60,000 lb/hr) watertube retrofit for CWM firing	-- Baseline (CWM)	Boiler outlet -- SASS -- VOST -- Method 5/8 -- Grab sample (C_1-C_6 HC) -- Grab sample N_2O -- Continuous NO_x, CO, CO_2, O_2, TUHC, SO_2 Fuel	EPRI, E. I. DuPont

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SECTION 2

SOURCE DESCRIPTION AND OPERATION

The tests were performed on a natural draft, crude-oil process heater located at the TOSCO oil refinery in Bakersfield, California. The heater has a rated maximum firing rate of 16 MW (55 million Btu/hr) heat input. The heater is fired by six John Zink DBA-22 natural draft burners, which are combination oil/gas burners with a turndown ratio of 3:1. Testing was performed with the unit firing approximately a 64/36 (heat input basis) refinery gas/oil mixture. All six burners were firing reabsorber gas from the plant. However only four were cofiring oil during the tests due to plugged oil guns in the other two burners which could not be cleaned in time for the tests. This unit normally fires exclusively reabsorber gas during the summer (when tests were performed) since it is in plentiful supply as a result of normal refinery operations at this time of year.

Figure 2-1 is a schematic diagram of the process heater. The sampling ports were located approximately 6 stack diameters from the damper which is not enough to establish a uniform velocity profile. This is supported by preliminary traverse data which indicated that the flow was predominately on one side of the stack (reference 2-1). Table 2-1 summarizes the boiler operating data for both tests. As noted, the heater was firing about 64 percent reabsorber gas and 36 percent oil (by heat input for both tests). The fuel flowrates remained essentially constant throughout the tests. There

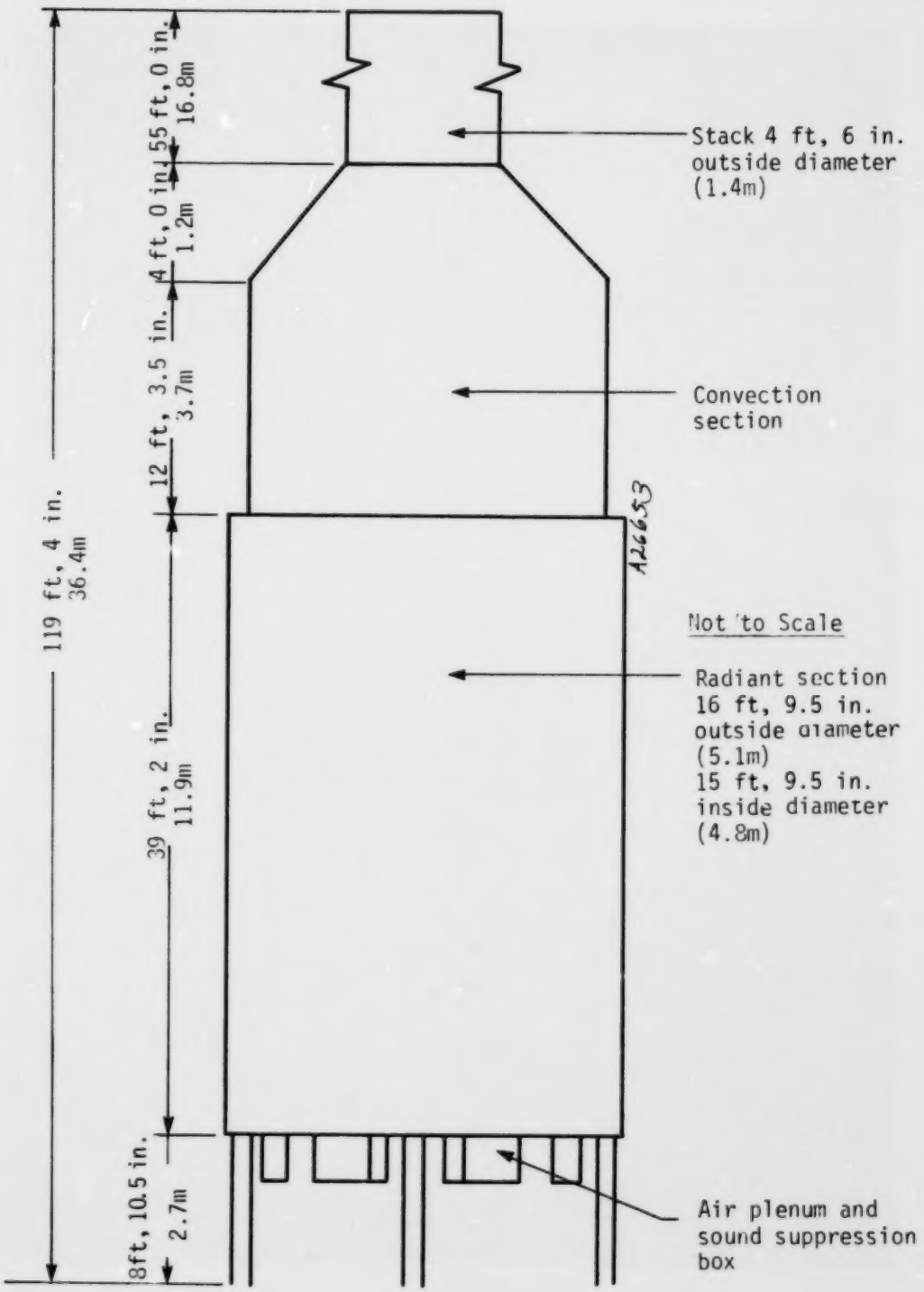

Figure 2-1. Schematic of the Crude-Oil Heater Tested

Table 2-1. Heater Operating Conditions

	Baseline	Low NO_x
Process rate, l/s (bbl/day)	21.5 (11,640)	21.5 (11,640)
Reabsorber gas		
Flowrate m^3/min (scfm)	7.1 (251)	7.1 (251)
Heat input MW (million Btu/hr)	8.35 (28.5)	8.13 (27.7)
Fuel oil		
Flowrate kg/min (lb/min)	6.59 (14.5)	6.55 (14.4)
Heat input MW (million Btu/hr)	4.77 (16.3)	4.75 (16.2)
Temperatures, °C (°F)		
Crude in	196 (384)	196 (384)
Crude out (east)	338 (641)	339 (642)
Crude out (west)	336 (637)	339 (642)
Tube 13, pass A	403 (758)	405 (761)
Tube 13, pass B	407 (764)	395 (743)
Tube 15, pass A	391 (735)	387 (728)
Tube 15, pass B	373 (704)	373 (704)
Tube 20, pass A	397 (746)	395 (743)
Tube 20, pass B	411 (772)	395 (743)
Tube 25, pass A	411 (771)	406 (762)
Tube 25, pass B	416 (780)	408 (766)
Pressures, kPa, (psig)		
Crude in (east)	960 (140)	960 (140)
Crude in (west)	896 (130)	896 (130)
Crude out	227 (33)	234 (34)
Burner - oil[a]	324 (47)	324 (47)
Burner - steam[a]	537 (78)	537 (78)
Burner - gas[b]	30 (4.4)	30 (4.3)
Gas pressure to heater	234 (34)	241 (35)
Excess air (percent)[c]	22	17

[a]Average of four burners using oil
[b]Average of all six burners
[c]Calculated from fuel analyses and flue gas O_2 measurements

were no significant changes in the operating conditions of the heater which would affect the crude oil flowing through it.

The-low NO_x test used a system of air injection lances to effect staged combustion for NO_x control. Figure 2-2 presents a schematic of the system which consists of a fan to supply air to the lances, a manifold and associated tubing, and 24 (4 per burner) variable-height lances (reference 2-2). The lances consist of vertical tubes of 316 stainless steel, having a 3.18-cm (1.25-in.) outer diameter with a 45° elbow near the end. The elbow provides better mixing across the flame. Although the air lances are capable of delivering half of the stoichiometric combustion air, they delivered 44 percent during the test. The rest of the combustion air is delivered through secondary air registers located at the base of the heater. Air flow through the heater is controlled by the stack damper located above the convection section.

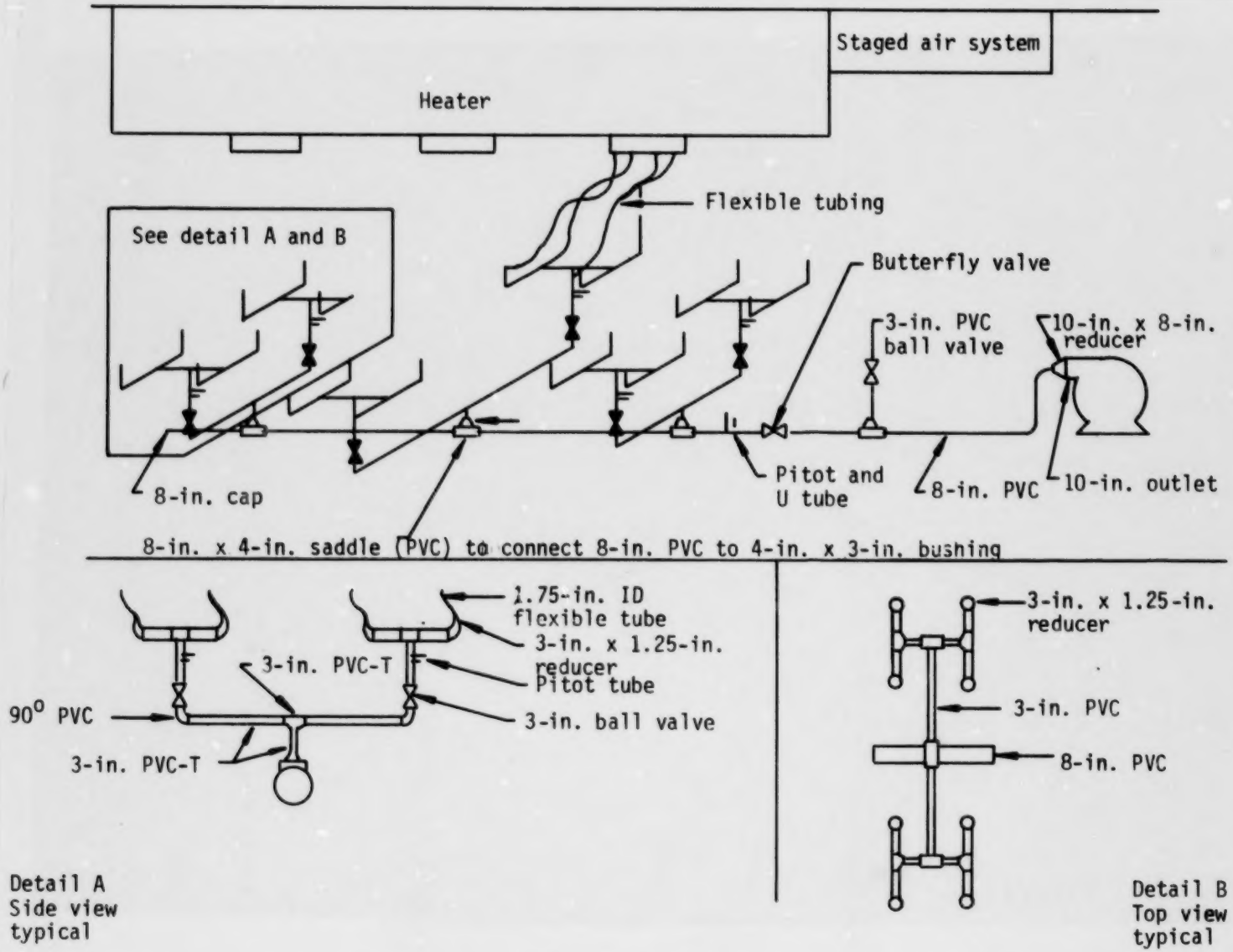

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Figure 2-2. Flow Schematic of Staged Combustion Air System for a Natural Draft Process Heater

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SECTION 3

EMISSION RESULTS

The objective of this test program was to measure flue gas emissions from a crude-oil heater in an "as-found" (baseline) configuration and using staged combustion for NO_x control via air injection lances. Table 3-1 summarizes the flue gas emissions measurements made by Acurex and the test collaborator KVB, Inc. Figure 3-1 shows the sampling locations. Succeeding discussion of the measurement results has been arranged by pollutant grouping. Criteria and other gas phase emissions are discussed in section 3.1, inorganic trace elements in section 3.2, organic species in section 3.3, and radionuclides in section 3.4. Section 4 presents an environmental assessment of the emissions and the results of biological testing of the organic sample extracts.

3.1 CRITERIA AND OTHER GAS PHASE SPECIES EMISSION RESULTS

Table 3-2 summarizes gaseous and particulate emissions measured during both the baseline and staged combustion tests. Continuous monitors (described in appendix A) were used to measure O_2, CO_2, CO, NO_x, and SO_2 emissions. The only significant changes in these measurements between the two tests were decreases in O_2 and NO_x. Emissions of other species remained relatively unchanged. The average O_2 level in the low-NO_x test was 3.3 percent compared to a baseline level of 4.0 percent. The NO_x reduction for this test was 31 percent, a decrease to 118 ppm from a baseline level of 172 ppm (at 3 percent O_2, dry). In previous tests, KVB has achieved 64 percent NO_x reductions

Table 3-1. Flue Gas Measurements

Pollutant	Measurement Technique[a]
NO_x, O_2, CO_2, CO, SO_2	Continuous monitors[b]
Particulate matter	EPA Method 5
SO_2/SO_3	Controlled condensation
C_1-C_6 hydrocarbons	Gas chromatography
Volatile and condensable organic species, trace elements	Source Assessment Sampling System (SASS)

[a]Measurement and analysis techniques are discussed in detail in appendix A
[b]Performed by KVB

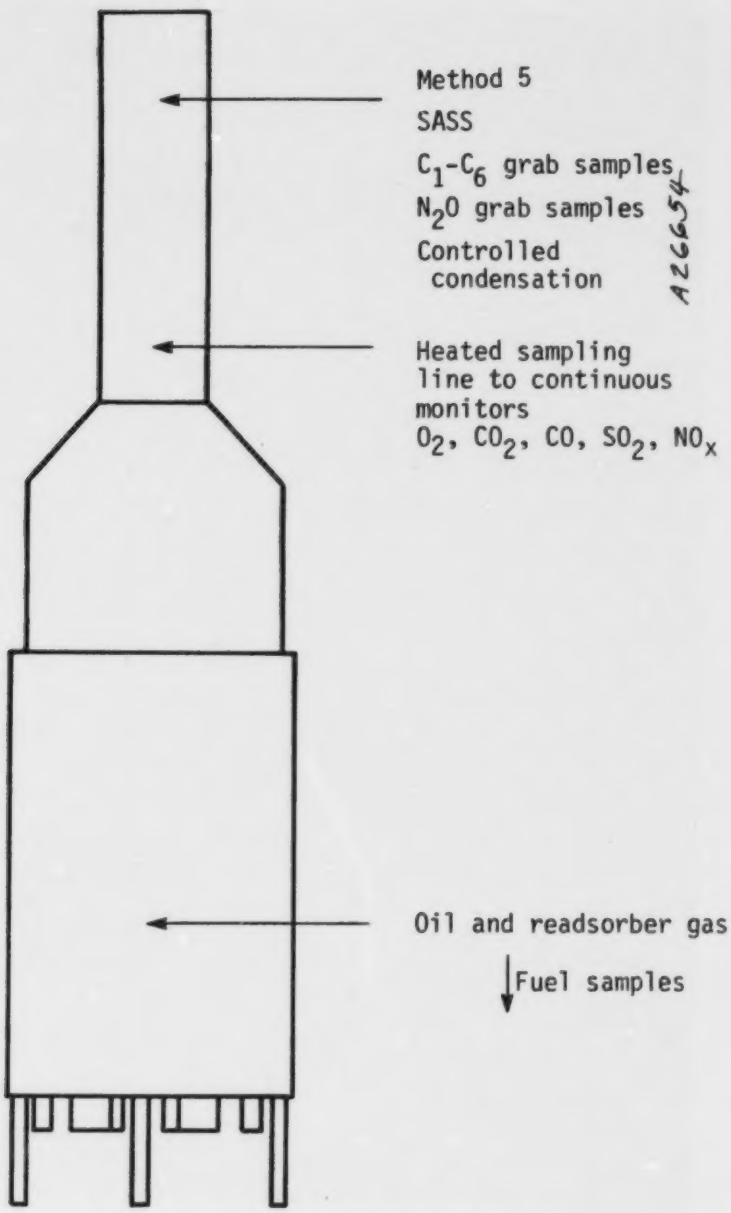


Figure 3-1. Refinery Crude Heater Sampling Locations (Sketch not to Scale)

Table 3-2. Gaseous Emissions

As Measured	Baseline		Low NO_x	
	Range	Average	Range	Average
O_2, percent (dry)	3.3 to 4.3	4.0	3.1 to 4.2	3.3
CO_2, percent (dry)	10.5 to 13.6	12.1	11.3 to 12.4	11.7
CO, ppm (dry)	0 to 10	3.8	0 to 10	3.4
NO_x, ppm (dry)	152 to 174	162	108 to 125	116
SO_2, ppm				
Continuous monitor (wet)	120 to 170	151	125 to 170	148
Controlled condensation (dry)	--[a]	97	--	115
SO_3				
Controlled condensation, ppm (dry)	--	2.4	--	1.8
Water, percent	--	15.9	--	16.5
N_2O, ppm (wet)	--	47.1	--	27.15
Vapor phase organics (C_1-C_6) mg/dscm	--	16.3	--	2.8
Semivolatile organics (TCO), mg/dscm	--	0.4	--	0.08
Nonvolatile organics (Gravimetric), mg/dscm	--	0.4[b]	--	0.5

Corrected	ppm[b]	ng/J	lb/10^6 Btu	ppm[b]	ng/J	lb/10^6 Btu
CO	4.0	1.19	0.0028	3.5	0.99	0.0023
NO_x (as NO_2)	172	83	0.19	118	56	0.13
N_2O	59	27	0.064	33	15	0.0315
SO_2						
Continuous monitor	190	128	0.30	180	118	0.27
Controlled condensation	103	69	0.16	117	77	0.18
SO_3						
Controlled condensation	2.5	2.1	0.0049	1.8	1.5	0.0035
	mg/dscm			mg/dscm		
Particulate -- Method 5						
Solid	31.1	8.35	0.019	20.0	5.0	0.012
Condensable	9.4	2.52	0.0059	3.2	0.80	0.0019
Particulate -- SASS	8.7	2.34	0.0054	8.1	2.0	0.0046
Vapor phase organics (C_1-C_6)	16.3	4.4	0.010	2.8	0.72	0.0017
TCO	0.4	0.11	0.00019	0.09	0.022	0.000023
Gravimetric	0.4	0.11	0.00026	0.5	0.13	0.00030

[a]Extractive sample
[b]At 3 percent O_2, dry

although these were with 100 percent refinery gas firing (references 3-1 and 3-2).

Since the nitrogen content of the oil was the same for the two tests (0.83 percent measured for the baseline and 0.85 percent measured for the low NO_x as shown in table 3-3), the reduction in NO_x can be essentially attributed to the staging provided by the air lances. Similar to the NO_x trend, N_2O emissions decreased from 59 to 33 ppm (at 3 percent O_2, dry) from the baseline to low-NO_x tests. CO levels dropped slightly, from 4.0 to 3.5 ppm (at 3 percent O_2, dry).

Sulfur species emissions were measured by continuous monitors (SO_2), a controlled condensation train (SO_2 and SO_3), and SASS (particulate sulfur). As shown in table 3-2, SO_2 emissions, as measured by continuous monitors decreased from 190 ppm (at 3 percent O_2, dry) in the baseline test to 180 ppm (at 3 percent O_2, dry) in the low-NO_x test. The controlled condensation train measurements showed an increase from 103 ppm to 117 ppm (both at 3 percent O_2, dry) between the baseline and low-NO_x tests. However, the relative magnitude of change for each method is small enough that a conclusion that SO_2 emissions were unchanged is warranted. The fact that the sulfur content of the fuel oil was measured to be 0.94 percent for the baseline and 0.90 percent for the low-NO_x test, supports this conclusion. SO_3 emissions, as measured by the controlled condensation train, decreased from 2.5 ppm to 1.8 ppm (at 3 percent O_2, dry) although, again, the magnitude of this change is insignificant. Particulate sulfur emissions for both tests were reported as greater than 0.56 µg/dscm because the sulfur concentration in the SASS filter catch exceeded the upper measurement limit of the spark source mass spectrometry (SSMS) analysis methodology. Based on the above information, table 3-4 presents a sulfur mass balance for the two tests. In both tests,

Table 3-3. Fuel Analyses

	Baseline	Low NO_x
Fuel gas (percent by volume)		
Hydrogen	8.7	9.3
Nitrogen	1.1	0.8
Carbon monoxide	0.4	0.5
Methane	22.7	24.5
Ethane	16.7	16.5
Ethylene	3.8	4.0
Propane	29.2	28.5
Propylene	3.3	3.6
Isobutane	11.1	9.5
n-butane	1.7	1.3
Total butenes	0.5	0.7
Isopentane	0.2	0.2
n-pentane	0.1	0.1
C_6 plus	0.5	0.5
Heating value, MJ/m^3 (Btu/ft^3)	70.56 1,892	68.71 1,842.6
Oil (percent by weight)		
Carbon	87.37	86.66
Hydrogen	10.47	10.98
Oxygen (by difference)	0.39	0.61
Nitrogen	0.83	0.85
Sulfur	0.94	0.90
Heating value, MJ/kg (Btu/lb)	43.44 18,720	43.54 18,760

Table 3-4. Sulfur Balance (g/s as Sulfur)

Fuel	Baseline		Low NO_x	
	In	Out	In	Out
	1.03		0.98	
Flue gas				
SO_2[a]		0.84		0.77
SO_3[b]		0.01		0.01
Particulate		>2 x 10^{-6}		>2 x 10^{-6}
Totals	1.03	0.85	0.98	0.78
Balance (out/in)	82 percent		80 percent	

[a]From continuous monitor
[b]From controlled condensation

approximately 80 percent of the sulfur is accounted for. The imbalance is probably attributable to inaccuracies in estimation of the fuel flowrates, rather than the particulate sulfur measurements (the balance increases to only 93 percent in the baseline test if it is assumed that all the solid particulate collected in the Method 5 train were sulfur, an unlikely possibility).

Because of the small amount of particulate expected from burning oil and gas, no particulate size fractionation was done in the SASS train. However, particulate emissions, as measured by both SASS and Method 5, showed a decrease for the low-NO_x test. SASS particulate dropped from 8.7 to 8.1 mg/dscm (at 3 percent O_2), while the solid particulate measured by Method 5 dropped from 31.1 to 20.0 mg/dscm (at 3 percent O_2) and condensable particulate decreased from 9.4 to 3.2 mg/dscm (at 3 percent O_2). The significant discrepancy between the SASS and the Method 5 results is most likely due to the proximity of the sampling location to a flow disturbance. For this reason the multipoint Method 5 result is more reliable than the single-point SASS result.

3.2 TRACE ELEMENT EMISSION RESULTS

The SASS train samples from the heater outlet were analyzed for 73 trace elements using Spark Source Mass Spectrometry (SSMS) and Atomic Absorption Spectroscopy (AAS). Once the trace element concentrations were determined by laboratory analysis, trace element flowrates for the flue gas vapor and condensed phases could be computed. Appendix B presents trace element concentrations in the SASS components and in the gas stream as well as flowrates on a mass per time and mass per heat input basis.

Table 3-5 summarizes the trace element concentrations which exceeded the lower detectability limits in either test. The elements calcium,

Table 3-5. Flue Gas Trace Element Emissions[a]

Element	Emissions		Element	Emissions	
	Baseline (µg/dscm)	Low NO_x (µg/dscm)		Baseline (µg/dscm)	Low NO_x (µg/dscm)
Aluminum	--[b]	80	Neodymium		
Antimony	<0.97	<0.96	Nickel	>30	29
Arsenic	<0.97	<0.96	Niobium	0.35	2.7
Barium	6.6	15	Osmium		
Beryllium	<0.004	<0.0004	Palladium		
Bismuth			Phosphorus	0.012	33
Boron	>1.8	--	Platinum	--	--
Bromine	6.6	22	Potassium	110	1,100
Cadmium	0.0004	0.47	Praseodymium	--	--
Calcium	--	380	Rhenium		
Cerium	--	1.2	Rhodium		
Cesium	0.18	<0.47	Rubidium	0.18	<2.5
Chlorine	100	66	Ruthenium		
Chromium	4.2	28	Samarium		
Cobalt	0.039	0.079	Scandium	--	<0.13
Copper	7.4	52	Selenium	<0.71	0.0016
Dysprosium			Silicon	750	770
Erbium			Silver	0.0036	6.8
Europium			Sodium	>910	>690
Fluorine	180	0.47	Strontium	14	2.3
Gadolinium			Sulfur	>880	>1,600
Gallium	0.18	0.0016	Tantalum		
Germanium	--	0.00040	Tellurium	0.0004	<0.54
Gold	--	--	Terbium		
Hafnium	--	--	Thallium		
Holmium			Thorium	--	0.0012
Iodine	0.27	0.94	Thulium		
Iridium			Tin	<0.0004	0.0004
Iron	28	190	Titanium	5.3	5.4
Lanthanum	--	2.7	Tungsten		
Lead	0.0093	1.2	Uranium	--	0.0012
Lithium	0.038	0.0060	Vanadium	0.81	1.7
Lutetium			Ytterbium	--	
Magnesium	0.89	9.4	Yttrium		0.27
Manganese	1.3	11	Zinc	12	95
Mercury	<0.71	<0.32	Zirconium	0.94	8.5
Molybdenum	0.015	3.0			

[a]Blanks indicate concentration below the detection limit of the sampling and analysis protocol

[b]Measured concentration less than concentration in blank

chlorine, fluorine, iron, potassium, silicon, sodium, and sulfur were detected at concentrations exceeding 0.1 mg/dscm in at least one of the tests. Of these eight elements, two (sodium and sulfur) could not be quantified because the concentration in the sample exceeded the upper quantification limit of the SSMS technique.

Table 3-6 summarizes the changes in trace element concentrations measured in each test. This information identifies those trace elements whose concentration differed by more than a factor of three (the accuracy of Level 1 analysis) between the two tests. Of the 48 trace elements detected at greater than the limit of the analysis method, emission levels of nine were within a factor of three between the two tests, six were higher in the baseline test, 25 were higher in the low-NO_x test, and the changes in eight were indeterminate. Roughly half of the trace element concentrations which differed by more than a factor of three between the two tests, differed by a factor of 10 or more (four out of six of those higher in the baseline and 12 out of 25 of those higher in the low-NO_x).

Table 3-7 presents the trace element mass balance for the baseline test, based upon the SSMS analysis of the fuel oil and the SASS components. From the table, it is apparent that for only three elements do the inlet and outlet balance within a factor of three, which is the limit of Level 1 accuracy. The oil analysis results are probably high for chromium, nickel, and iron, due to potential contamination from the Parr bomb ashing of the oil for SSMS analysis. However, the mass balance does indicate six elements which were detected in the fuel but not in the outlet, and 15 elements which were detected at the outlet, but not in the fuel.

Table 3-8 presents the trace element mass balance for the low-NO_x test. For this test, only two elements are detected in the fuel but not the exhaust,

Table 3-6. Relative Trace Element Concentrations Between the Baseline and Low-NO_x Tests

Unable to Determine	Higher in Baseline By a Factor of >3[a]	Within Factor of 3 Between Tests[b]	Higher in Low NO_x By a Factor of >3[a]
Cs	Be*	Sb	Al
Ni	B*	As	Ba
Rb	F*	Cl	Br
Se	Ga*	Co	Cd*
Na	Li	Hg	Ca*
S	Sr	Mo	Ce*
Te		Si	Cr
Sn		Ti	Cu
		V	Ge*
			I
			Fe
			La*
			Pb*
			Mg*
			Mn
			Nb
			P*
			K*
			Sc*
			Ag*
			Th
			U*
			Y
			Zn
			Zr

[a]An asterisk indicates where the concentration differed by a factor of greater than 10

[b]Changes in concentration within a factor of 3 indicated that the concentrations are equal within the accuracy of the analysis

Table 3-7. Baseline Test Trace Element Mass Balance

Element	Oil (µg/s)	Heater Outlet (µg/s)	Mass Balance (Out/In)
Aluminum	1,600	0.1	0.000062
Antimony		<3.4	*[b]
Arsenic		<3.4	*
Barium	220	23	0.10
Beryllium		<0.014	*
Boron	11	>630	>5.7
Bromine	55	2.3	0.43
Cadmium		0.0014	*
Calcium	3,300		0
Cesium		0.62 to 2.3	*
Chlorine	220	360	1.6
Chromium	66	15	0.22
Cobalt	<11	0.14	>0.012
Copper	770	26	0.034
Fluorine	22	620	28
Gallium	33	0.63	0.019
Germanium			*
Iodine	11	0.94	0.86
Iron	1,400	99	0.070
Lead	22	0.33	0.015
Lithium	98	0.13	0.0014
Magnesium	1,100	3.1	0.0028
Manganese	77	4.5	0.058
Mercury	N[a]	<2.5	*
Molybdenum		0.054	*
Nickel	880	>110	>0.12
Niobium		1.2	*
Phosphorus	990	0.043	0.000043
Platinum	220		0
Potassium	8,700	400	0.045
Rubidium		0.62 to 2.3	*
Scandium	<11		0
Selenium		<2.5	*
Silicon	4,900	2,650	0.54
Silver		0.013	*
Sodium	<11	>3,200	>290
Strontium	11	50	4.6
Sulfur	>35,000	>3,100	*
Tellurium		0.0014	*
Thorium	<44		0
Tin		<0.0014	*
Titanium	660	19	0.028

[a]Not determined
[b]Unable to determine

Table 3-7. Concluded

Element	Oil (µg/s)	Heater Outlet (µg/s)	Mass Balance (Out/In)
Uranium	<55		0
Vanadium	220	2.8	0.013
Yttrium	22		0
Zinc	980	43	0.044
Zirconium	88	3.3	0.038

Table 3-8. Low NO_x Test Trace Element Mass Balance[a]

Element	Oil (µg/s)	Heater Outlet (µg/s)	Mass Balance (Out/In)
Aluminum	1,420	260	0.19
Antimony		<3.2	*[c]
Arsenic		<3.1	*
Barium	190	49	0.45
Beryllium		<0.0013	*
Boron	110		0
Bromine		68 to 77	*
Cadmium		1.5	*
Calcium	1,750	1,260	0.72
Cerium		4.0	*
Cesium		<1.5	*
Chlorine	550	2,200	4.0
Chromium	110	91	0.83
Cobalt	<22	0.26	0.012
Copper	660	170	0.26
Fluorine	44	1.5	0.035
Gallium	11	0.0053	0.00048
Germanium		0.0013	*
Iodine		3.1	*
Iron	2,800	630	0.22
Lanthanum		8.9	*
Lead	98	4.1	0.041
Lithium	220	0.02	0.000091
Magnesium	1,310	31	0.0023
Manganese	55	37	0.68
Mercury	N[b]	<1.05	*
Molybdenum		9.8	*
Nickel	870	96	0.11
Niobium		8.9	*
Phosphorus	550	110	0.20
Platinum	1,200		0
Potassium	7,210	3,630	0.50
Rubidium		<8.2	*
Scandium		<0.44	*
Selenium		0.0053 to 8.9	*
Silicon	1,750	2,550	1.5
Silver		22	*
Sodium	660	>2,300	>3.5
Strontium	56	7.6	0.14
Sulfur	3,600	>5,300	>1.5

[a]Blanks indicate elements below the detection limit; trace elements not listed were not detected in either the inlet or outlet

[b]Not analyzed

[c]Unable to determine

Table 3-8. Concluded

Element	Oil (µg/s)	Heater Outlet (µg/s)	Mass Balance (Out/In)
Tellurium		<1.8	*
Thorium	<98	0.0040	0.000040
Tin		0.0013	*
Titanium	1,100	18	0.016
Uranium	<88	0.0040	0.000045
Vanadium	87	5.5	0.063
Yttrium		0.89	*
Zinc	330	310	0.95
Zirconium		28	*

while 19 are detected in the exhaust but not the fuel. However, eight trace elements (Ba, Zn, Mn, Cr, Ca, K, Cl and Si) balanced within a factor of three. The same potential contamination problem with iron, nickel, and chromium in the oil sample still exists, so those results should be treated with suspicion.

For both sets of data, some of the concentrations were indeterminate because the sample and blank concentrations were both reported as larger than the upper quantitation limit of the SSMS methodology.

3.3 ORGANIC EMISSION RESULTS

Organic analyses were performed on selected SASS samples according to EPA Level 1 protocol (reference 3-3), as outlined in appendix A. Volatile organic species having boiling points nominally in the C_1-C_6 range of -106° to 32°C (-160° to 90°F) were determined by onsite gas chromatographic analyses of grab samples. SASS samples were extracted with methylene chloride in a soxhlet apparatus. Semivolatile organic matter with boiling points nominally in the C_7-C_{16} range of 32° to 300°C (90° to 572°F) were determined in the laboratory by total chromatographable organic (TCO) analysis of the organic module sorbent (XAD-2) and condensate sample extracts. Nonvolatile organic species having boiling points nominally in the greater than C_{17} range of >300°C (>572°F) were measured by gravimetric analysis of SASS sample extracts including filter catches.

Infrared spectrometry (IR) was also performed on the gravimetric residue filter catch and organic module sorbent extracts to identify organic functional groups present. If certain TCO and gravimetric criteria were met, further analysis by low resolution mass spectrometry (LRMS) was performed. In addition, specific polynuclear aromatic and selected other organic species

were identified by gas chromatography/mass spectrometry (GC/MS) analysis of total sample extracts. A discussion of the analytical results follows.

3.3.1 C_1-C_6 Hydrocarbon, TCO, and Gravimetric Analyses

As indicated in table 3-9, vapor-phase hydrocarbon (C_1-C_6) emissions decreased from 16.3 mg/dscm under baseline conditions to 2.8 mg/dscm under low-NO_x conditions. In the baseline test, they were somewhat evenly divided among the C_2, C_3, and C_4 boiling point ranges while the low-NO_x test produced only nominal C_2 hydrocarbons. Total organic emissions in both tests were dominated by the C_1-C_6 fraction; these accounted for 95 percent in the baseline and 73 percent in the low-NO_x test.

Table 3-9 also summarizes organic emission results from the TCO and gravimetric analyses. The TCO results have been compromised somewhat in these tests due to the use of XAD-2 resin which had been inadvertantly contaminated by acetone between resin preparation and eventual use. Thus, several acetone solvent contaminants and acetone dimerization products, all of low-molecular weight and in the TCO boiling point range, were introduced into the resin. This resulted in a high TCO blank for the XAD-2 resin for both tests. Table 3-10 shows the sample extract and field blank TCO values from both tests, and indicates the high, contaminated blank.

In an attempt to correct for the high blank, GC/MS analyses of the extracts were performed to identify and quantitate specific contaminant species in both the blank and sample extracts. Subtracting the amount of these contaminant species found in both sample and blank extracts from the TCO levels of each, allowed defining a corrected TCO value for both samples and the blank. These corrected levels are also shown in table 3-10. TCO values listed in table 3-9 reflect these corrected values. It should be noted that

Table 3-9. Summary of Total Organic Emissions

Organic Emissions	Baseline (mg/dscm)	Low NO_x (mg/dscm)
Volatile organic gases analyzed in the field by gas chromatography:		
C_1	0	0
C_2	3.6	2.8
C_3	4.8	0
C_4	6.4	0
C_5	1.5	0
C_6	0	0
Total C_1-C_6	16.3	2.8
Volatile organic material analyzed by TCO:		
XAD-2	0.36	0.06
Organic module condensate	<0.001	0.02
Total C_7-C_{16}	0.36	0.08
Nonvolatile organic material analyzed by gravimetric procedure:		
Filter	<0.2	<0.3
XAD-2	0.4	0.3
Organic module condensate	<0.1	0.2
Total C_{16+}	0.4	0.5
Total organics	17.1	3.4

Table 3-10. XAD-2 Extract TCO Results

	Baseline TCO (mg)	Low-NO_x TCO (mg)
Uncorrected		
Sample extract	39	25
Blank	30	30
Sample	9	<5
Corrected		
Sample extract	11	2.3
Blank	0.5	0.5
Sample	10.5	1.8

all contamination consisted of TCO boiling range compounds so gravimetric results should be unaffected.

The data shown in table 3-9 suggest that emissions of C_{7+} organics are unchanged with firing mode. Again, these data are compromised to some degree because of the resin contamination. However, given the GC/MS corrective procedure employed, the data are defensible.

In order to evaluate the overall reliability of the organic extraction and analysis procedure, a sample of clean (and uncontaminated) XAD-2 was spiked with 1.0 mg of TCO material. Extraction, concentration, and TCO analysis of this spiked sample gave 0.74 mg implying a 74 percent recovery by the procedure.

No liquid chromatography (LC) fractionation of extracts was performed for these tests, since the TCO + gravimetric organic content of no extract sample exceeded the LC fractionation criterion of 15 mg.

3.3.2 IR Spectra of Total Extracts

IR spectrometry was used to identify organic functional groups present in SASS samples. Table 3-11 summarizes the results of these analyses for the filter, XAD-2, and the organic module condensate extracts for both tests. Only the XAD-2 extract from the baseline test showed measurable absorbances. These were characteristic of aliphatic hydrocarbons.

3.3.3 Low Resolution Mass Spectrometry (LRMS) of Total Extracts

Table 3-12 presents the results of direct-insertion probe LRMS of the total XAD extracts from both tests. Table 3-13 lists the compound classes and fragment ions used to identify compound categories present. In the baseline test, ethers, heterocyclic sulfur compounds, and carboxylic acids are major components indicated, while halogenated aliphatics, aromatic hydrocarbons, nitriles, alcohols, and heterocyclic nitrogen compounds are minor categories

Table 3-11. Summary of IR Analyses of SASS Sample Total Extracts

Baseline		
SASS Component	Frequency (cm^{-1})	Assignment
Filter	--	No Peaks
XAD-2	2,920	CH Alkane
	2,840	CH Alkane
OMC	--	No Peaks
Low NO_x		
SASS Component	Frequency	Assignment
Filter	--	No Peaks
XAD-2	--	No Peaks
OMC	--	No Peaks

Table 3-12. Summary of LRMS Analyses of XAD-2 Extracts

Species Category	Intensity	Estimated Flue Gas Concentration (mg/dscm)
Baseline: TCO + Grav = 0.76 mg/dscm		
Ethers	100	0.22
Carboxylic acids	100	0.22
Heterocyclic sulfur compounds	100	0.22
Alkyl halides	10	0.02
Alcohols	10	0.02
Nitriles	10	0.02
Aromatic hydrocarbons	10	0.02
Heterocylic nitrogen compounds	10	0.02
Total	350	0.76
Low NO_x: TCO + Grav = 0.35 mg/dscm		
Alyphatic hydrocarbons	100	0.16
Amines	100	0.16
Carboxylic acids	10	0.02
Aromatic hydrocarbons	10	0.02
Total	220	0.36

Table 3-13. Compound Classes and Characteristic Fragment Ions Sought by Direct-Insertion Probe LRMS

Compound Class	Fragment Ions (m/e^-)
Polycyclic aromatic hydrocarbons	178, 202, 216, 228, 252, 276
Aliphatic hydrocarbons	57, 71
Halogenated aliphatics	79, 81, 93, 95, 107, 109, 49, 63
Aromatic hydrocarbons	50, 51, 77, 78, 79, 91
Ethers	45, 59, 73
Alcohols	45, 59, 61, 73, 75
Phenols	51, 77, 94
Nitriles	54, 68, 82
Phthalate esters	61, 59, 71, 87
Amines	44, 58
Ketones	51, 71
N-Heterocyclics	117, 167, 129, 179
Mercaptans, sulfides	47, 61, 75
Benzothiophenes	57, 58, 59, 69, 70, 85, 97, 111, 125
Carboxylic acids	60, 73, 149
Amides	58, 72, 86, 100

indicated. In the low-NO_x test, aliphatic hydrocarbons and amines are indicated as major components while aromatic hydrocarbons and carboxylic acids are indicated as minor components. The estimated emission level for each compound category detected, shown in table 3-12, was calculated by proportioning the total C_{7+} organic emission levels shown in table 3-9 among the intensities noted in table 3-12.

3.3.4 Gas Chromatography/Mass Spectrometry Analysis of XAD-2 Extracts

GC/MS analyses of the organic module extracts from the SASS train were performed to detect and quantify specific polycyclic organic materials (POM) and selected other organic compounds. The POM and other compounds sought in the analysis are listed in table 3-14 along with their detection limits in the GC/MS analyses. The results of the GC/MS analyses are summarized in table 3-15. Duplicate analyses of the low-NO_x XAD-2 extract were performed to assess the precision of the analyses. Table 3-15 shows that these agreed quite well. The average of these two analysis runs are used in the following comparison between baseline and low-NO_x emissions.

Eleven specific compounds were identified in concentrations ranging from <0.04 to 1.4 μg/dscm. In general, emissions of these species were lower in the low-NO_x test than the baseline. The general decrease in these semivolatile organic priority pollutant species emissions from a total of 4.1 μg/dscm to 1.9 μg/dscm is consistent with the decrease in total organic emissions noted previously.

Analysis of XAD-2 resin spiked with naphthalene, phenanthrene, and pyrene yielded recoveries of 33 percent, 38 percent, and <1 percent, respectively. This suggests that the uncertainty in the data presented in table 3-14 is approximately a factor of three, at least for the more volatile species analyzed for.

Table 3-14. Compounds Sought in the GC/MS Analysis and Their Detection Limits (ng/µl Injected)

Acid Compounds			
2,4,6-trichlorophenol	5	2-nitrophenol	5
p-chloro-m-cresol	5	4-nitrophenol	20
2-chlorophenol	5	2,4-dinitrophenol	20
2,4-dichlorophenol	5	4,6-dinitro-o-cresol	20
2,4-dimethylphenol	5	pentachlorophenol	5
		phenol	1

Base Neutral Compounds			
1,2,4-trichlorobenzene	1	benzo(c)phenanthrene	40
1,2-dichlorobenzene	1	bis(2-chloroethoxy)methane	1
1,2-diphenylhydrazine (as azobenzene)	1	bis(2-chloroethyl)ether	1
		bis(2-chloroisopropyl)ether	1
1,3-dichlorobenzene	1	bis(2-ethylhexyl)phthalate	1
1,4-dichlorobenzene	1	butyl benzyl phthalate	1
2,4-dinitrotoluene	1	chrysene	1
2,6-dinitrotoluene	1	di-n-butyl phthalate	1
2-chloronaphthalene	1	di-n-octyl phthalate	1
3,3'-dichlorobenzidine	5	dibenzo(a,h)anthracene	5
3-methyl cholanthrene	40	dibenzo(c,g)carbazole	40
4-bromophenyl phenyl ether	1	diethyl phthalate	1
4-chlorophenyl phenyl ether	1	dimethyl phthalate	1
7,12-dimethyl benz(a)anthracene	40	fluoranthene	1
N-nitrosodi-n-propylamine	5	fluorene	1
N-nitrosodimethylamine	NA	hexachlorobenzene	1
N-nitrosodiphenylamine	1	hexachlorobutadiene	1
acenaphthene	1	hexachlorocyclopentadiene	1
acenaphthylene	1	hexachloroethane	1
anthracene	1	indeno(1,2,3-cd)pyrene	5
benzo(ghi)perylene	5	isophorone	1
benzidine	20	naphthalene	1
benzo(b)fluoranthene	1	nitrobenzene	1
benzo(k)fluoranthene	1	perylene	40
benzo(a)anthracene	1	phenanthrene	1
benzo(a)pyrene	1	pyrene	1

Table 3-15. Results of the GC/MS Analyses

Species	Baseline (µg/dscm)	Low NO_x (µg/dscm)		
		Run 1	Run 2	Average
Phenol	1.0	0.20	0.55	0.4
Naphthalene	<0.04	0.40	0.78	0.6
1,3-dichlorobenzene	0.08	<0.04	<0.04	<0.04
1,4-dichlorobenzene	0.04	0.04	0.08	0.06
1,2-dichlorobenzene	0.1	<0.04	<0.04	<0.04
Nitrobenzene	0.2	0.04	0.08	0.06
2-nitrophenol	<0.2	0.43	0.39	0.41
Diphenylamine	0.1	0.08	0.08	0.08
1,2-diphenylhydrazine (as azobenzene)	1.4	<0.04	0.04	0.04
Phenanthrene	1.2	0.10	0.20	0.15
2,6-dinitrotoluene	<0.04	0.10	<0.04	0.07
Other polynuclears	<0.04	<0.04	<0.04	<0.04

3.4 RADIONUCLIDE EMISSION RESULTS

Portions of the SASS filters were analyzed for alpha, beta, and gamma activity. In both cases, the filter activities were less than or equal to the activity of the blank, as shown in table 3-16. Thus, there are no significant particulate radionuclide emissions from this source.

Table 3-16. Particulate Radioactivity

	Activity pCi/filter[a]		
	Gross Alpha	Gross Beta	Gross Gamma
Baseline	$\leq$ 18	60.6 $\pm$ 7.8	$\leq$ 143
Low NO_x	15 $\pm$ 12	75.0 $\pm$ 11.3	$\leq$ 143
Blank	$\leq$ 19	99.6 $\pm$ 13.5	$\leq$ 142

[a]The $\pm$ values are the 2 sigma Poisson standard deviation of the counting error.

REFERENCES FOR SECTION 3

3-1. Tidona, R. J., et al., "Refinery Process Heater NO_x Reductions Using Staged Combustion Air Lances," EPA-600/7-83-022, NTIS PB 83-193946, March 1983.

3-2. Hunter, S. C., W. A. Carter, and R. J. Tidona, "Control of NO_x Emissions from Petroleum Process Heaters Using Staged Air Lances," presented at the West Coast Section meeting of the Air Pollution Control Association, Palm Springs, CA, October 1981.

3-3. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level I Environmental Assessment (Second Edition)," EPA-600/7-78-201, NTIS PB 293795, October 1978.

SECTION 4

ENVIRONMENTAL ASSESSMENT

This section discusses the potential environmental significance of the refinery heater testing including bioassay testing. As a means to rank species discharged for possible further consideration, flue gas stream species concentrations are compared to occupational exposure guidelines. Bioassay analyses were conducted as a more direct measure of the potential health effects of the effluent streams. Both of these analyses are aimed at identifying potential problem areas and providing the basis for ranking pollutant species and discharge streams for further consideration.

4.1 EMISSIONS ASSESSMENT

To obtain a measure of the potential significance of the pollutant levels in the flue gas analyzed in this test program, flue gas concentrations were compared to an available set of health-effects-related indicies. The indices used for comparison were occupational exposure guidelines, specifically the time-weighted-average Threshold Limit Values (TLV's) defined by the American Conference of Governmental Industrial Hygienists (ACGIH) (reference 4-1).

The comparisons of the flue gas stream species concentrations to these indices should only be performed to rank species emission levels for further testing and analyses. Table 4-1 lists those pollutant species emitted at levels greater than 10 percent of their occupational exposure guidelines.

4.2 BIOASSAY RESULTS

Bioassay tests were performed on the organic sorbent (XAD-2) extracts. The bioassay tests performed were health effects tests only (reference 4-2). These were:

- Ames assay, based on the property of Salmonella typhimurium mutants to revert due to exposure to various classes of mutagens
- Cytotoxicity assay (CHO) with mammalian cells in culture to measure cellular metabolic impairment and death resulting from exposure to soluble toxicants

A detailed description of the biological analyses performed is presented in Volume II (Data Supplement) of this report.

Table 4-2 summarizes the results from the Ames and CHO assays. The XAD-2 extract showed moderate toxicity and moderate to high mutagenicity.

4.3 CONCLUSIONS

The use of staged air lances resulted in a decrease in NO_x emissions, with no significant adverse impacts. Particulate and organic emissions exhibited slight decreases while trace element emissions exhibited an apparent increase which may be only partially attributable to increases in the trace element concentrations in the fuel. Bioassay results of XAD-2 extracts indicated that the extracts were of moderate toxicity for both tests although the mutagenicity of the extracts increased from moderate for the baseline test to high for the low-NO_x test.

Table 4-1. Flue Gas Species Emitted at Levels Exceeding 0.1 of an Occupational Exposure Limit

Species	Flue Gas Concentration (μg/dscm)		Occupational Exposure Guideline ($\mu g/m^3$)[a]
	Baseline	Low NO_x	
SO_2	480,000	470,000	5,000
NO_x (as NO_2)	200,000	140,000	6,000
Silver, Ag	0.0036	6.8	10
Potassium, K[b]	110	1,100	2,000
Sodium, Na[b]	>910	>690	2,000
Phosphorus, P	0.012	33	100
Nickel, Ni	>3.0	29	100
Copper, Cu	7.4	52	200
Iron, Fe	28	190	1,000
Calcium, Ca[b]	<0.004	380[b]	2,000

[a]Threshold Limit Value (reference 4-1)
[b]True value probably higher; at least one component of the SASS train showed a sample and blank concentration higher than the upper quantification limit

Table 4-2. Bioassay Results

Test	Bioassay	
	Ames[a]	CHO[b]
XAD-2 extract:		
Baseline	M	M
Low NO_x	H	M

[a]M = Moderate mutagenicity, H = High mutagenicity
[b]M = Moderate toxicity

REFERENCES FOR SECTION 4

4-1. "Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1982," American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1982.

4-2. Brusick, D. J., and R. R. Young, "IERL-RTP Procedures Manual: Level 1 Environmental Assessment, Biological Tests," EPA-600/8-81-024, NTIS PB 228766, October 1981.

APPENDIX A

TEST EQUIPMENT AND PROCEDURES

A.1 CONTINUOUS MONITORING SYSTEM

KVB, Inc. provided continuous vapor phase species emissions monitoring for this test program using a rack-mounted monitor and recorders located in a mobile emission laboratory. A flow schematic of this flue gas sampling and analyzing system is shown in figure A-1. The sampling system uses one of three double-headed positive-displacement diaphragm pumps to continuously draw flue gas from the stack into the laboratory. The sample pumps pull from up to six unheated sample lines. Selector valves allow composites of up to six points to be sampled at one time. The probes are connected to the sample pumps with 0.95-cm (3/8-in.) or 0.64-cm (1/4-in.) nylon line. The positive-displacement diaphragm sample pumps provide unheated sample gas to the refrigerated condenser (to reduce the dew point to 1.7°C (35°F)), to a rotameter with flow control valve, and to the O_2, NO_x, CO, and CO_2 instrumentation. Flow to the individual analyzers is measured and controlled with rotameters and flow control valves. Excess sample is vented to the atmosphere.

To obtain a representative sample for the analysis of NO_2, SO_2, and hydrocarbons, the sample must be kept above its dew point, since both water and heavy hydrocarbons may be condensable, and SO_2 and NO_2 are quite soluble in water. For this reason, a separate electrically heated sample line is used

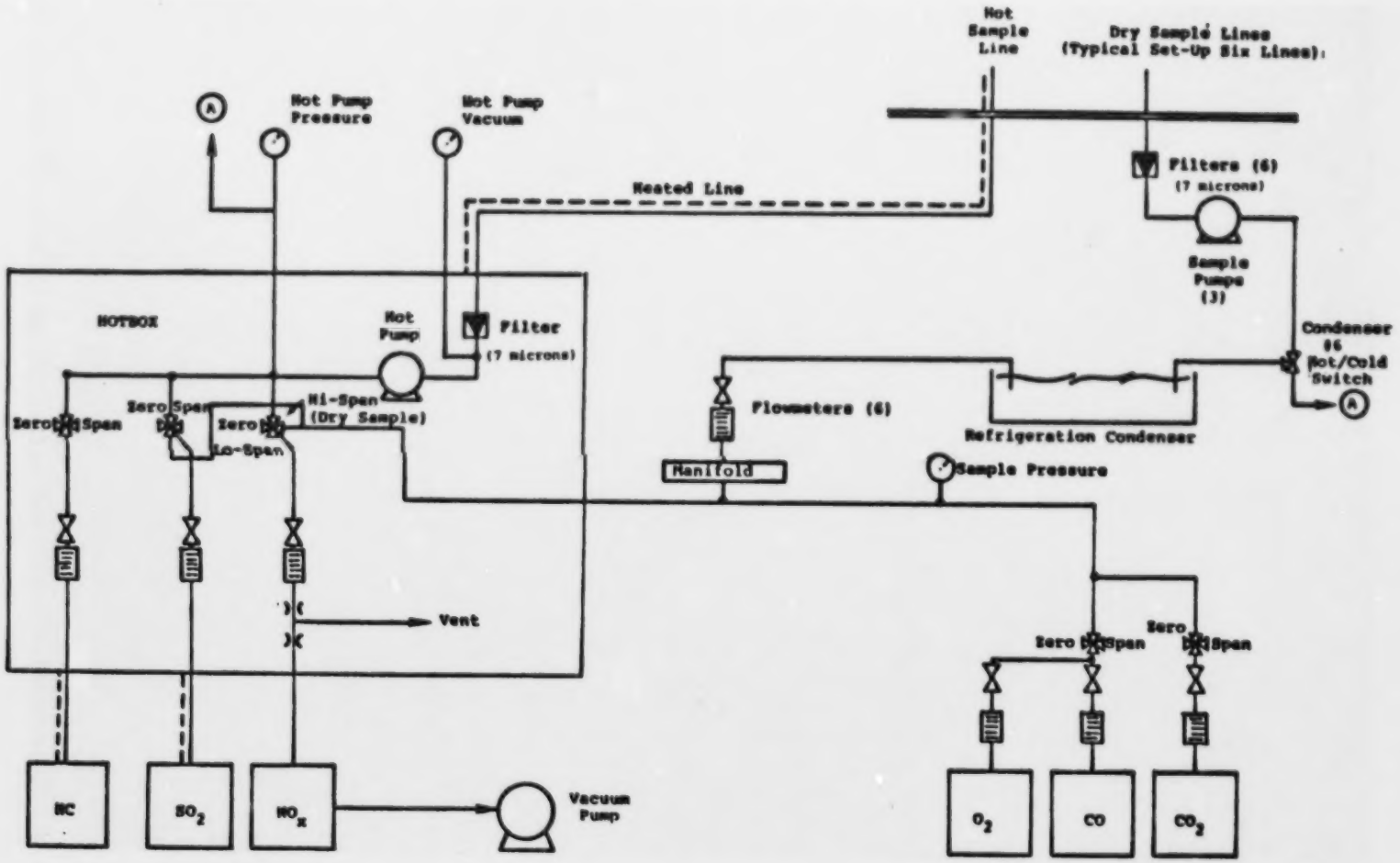


Figure A-1. Flue Gas Sampling and Analyzing System (Reference A-1)

to bring the sample into the laboratory for analysis. The sample line is 0.95-cm (3/8-in.) Teflon line, electrically traced and thermally insulated to maintain a sample temperature of up to 204°C (400°F). A heated diaphragm pump provides hot sample gas to the hydrocarbon, SO_2 and NO_x analyzers and cold, dried gas to the other continuous analyzers via the condenser previously described.

The laboratory trailer is equipped with the analytical instruments shown in table A-1 to continuously measure concentrations of NO, NO_2, CO, CO_2, O_2, SO_2, and hydrocarbons. All of the continuous monitoring instruments and sample handling system are mounted in the self-contained mobile laboratory. The instruments themselves are shock mounted on a metal console panel.

Due to the failure of the electronic datalogger just prior to the start of these tests, the gaseous emission measurements were determined by manually interpreting the stripchart recordings and recording 15-min averages.

A-2. PARTICULATE TESTS

Particulate mass emission tests were performed each day in accordance with EPA Methods 1 through 5. The sampling train used is illustrated in figure A-2. Both solid particulate matter collected in the filter ahead of

Table A-1. Emission Measurement Instrumentation

Species	Measurement Method	Manufacturer	Model No.
Carbon monoxide	IR spectrometer	Beckman Instruments	865
Oxygen	Polarographic	Teledyne	326A
Carbon dioxide	IR spectrometer	Beckman Instruments	864
Nitrogen oxides	Chemiluminescent	Thermo Electron Co.	10A
Sulfur dioxide	UV spectrometer	DuPont Instruments	400

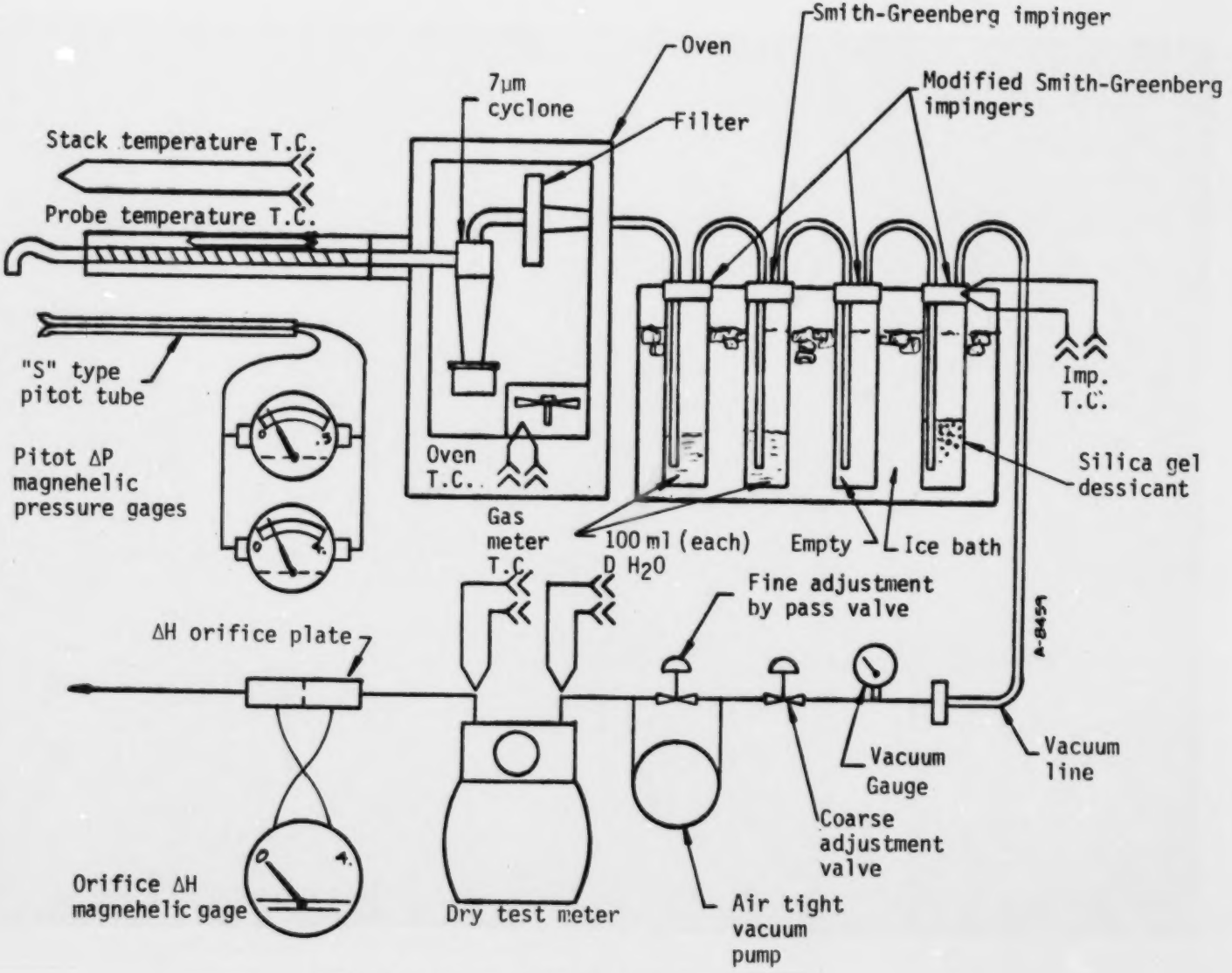


Figure A-2. Particulate Sampling Train

the impinger section and condensable particulate collected in the impingers were measured, as indicated in figure A-3.

A.3 SULFUR EMISSIONS

Sulfur emissions (SO_2 and SO_3) were measured using the controlled condensation system illustrated in figure A-4. This sampling system, designed primarily to measure vapor phase concentrations of SO_3 as H_2SO_4, consists of a heated Vycor probe, a condenser (condensation coil), impingers, a pump, and a dry gas test meter. By using the condenser, the gas is cooled to the dew point where SO_3 condenses as H_2SO_4. SO_2 interference is prevented by maintaining the temperature of the gas above the water dew point. Sulfur dioxide is collected in a 3 percent hydrogen peroxide solution. Both SO_2 and SO_3 (as H_2SO_4) are measured by titration with a 0.02 N NaOH solution using barium thorin as the indicator. A more detailed discussion of the sampling and analytical techniques for the controlled condensation system is given in reference A-2.

A.4 TRACE ELEMENTS AND ORGANIC EMISSIONS

Emissions of inorganic trace elements and organic compounds were sampled with a Source Assessment Sampling System (SASS). The SASS train was designed and built for EPA's Industrial Environmental Research Laboratory, Research Triangle Park, for Level 1 environmental assessment (reference A-3). It collects large quantities of gaseous and solid samples required for subsequent analyses of inorganic and organic emissions as well as particle size measurements.

The SASS system, illustrated in figure A-5, is generally similar to the system utilized for total particulate mass emission tests, with the exception of:

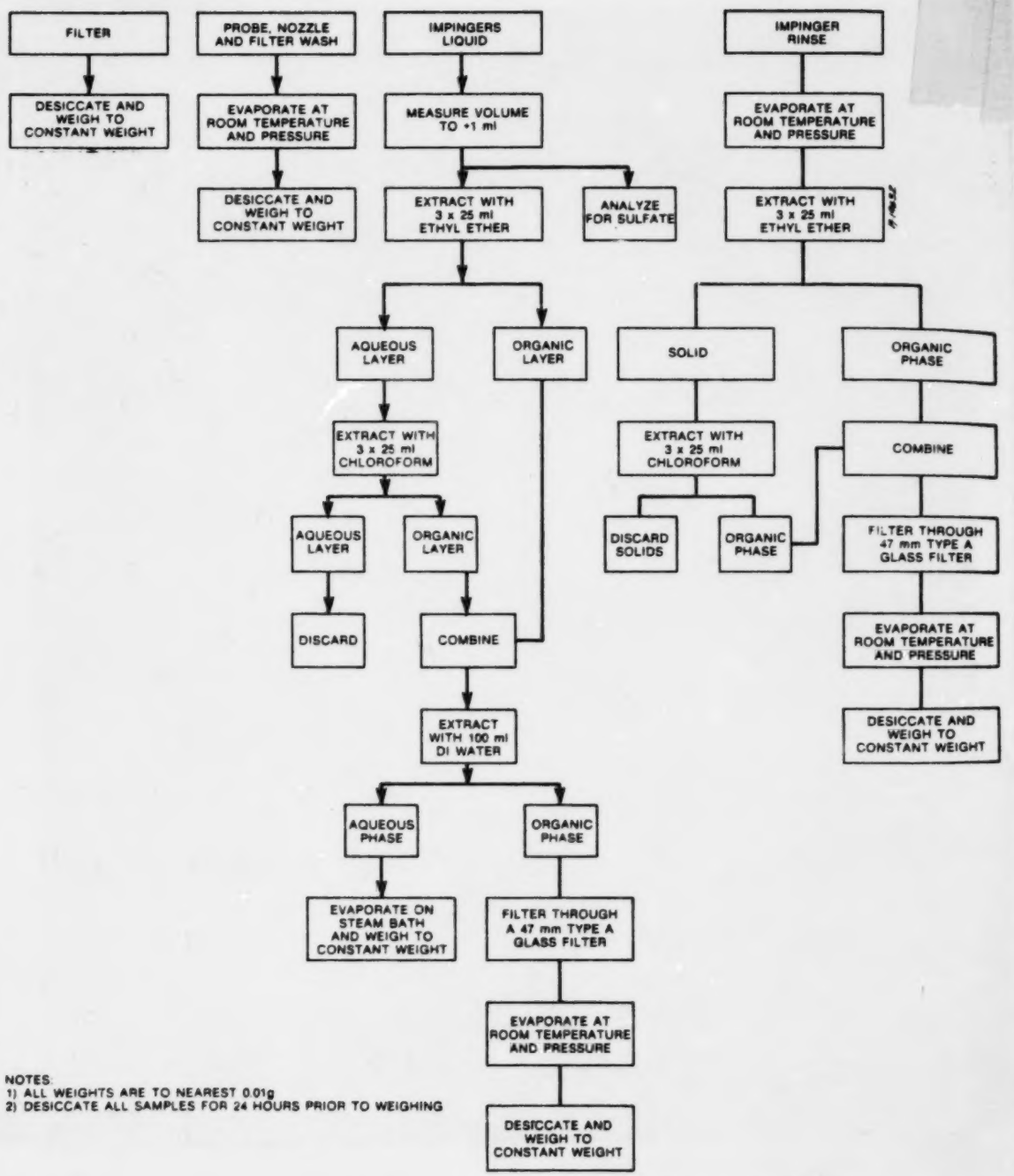

FILTER
PROBE, NOZZLE AND FILTER WASH
IMPINGERS LIQUID
IMPINGER RINSE
DESICCATE AND WEIGH TO CONSTANT WEIGHT
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
MEASURE VOLUME TO +1 ml
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
DESICCATE AND WEIGH TO CONSTANT WEIGHT
EXTRACT WITH 3 x 25 ml ETHYL ETHER
ANALYZE FOR SULFATE
EXTRACT WITH 3 x 25 ml ETHYL ETHER
AQUEOUS LAYER
ORGANIC LAYER
SOLID
ORGANIC PHASE
EXTRACT WITH 3 x 25 ml CHLOROFORM
EXTRACT WITH 3 x 25 ml CHLOROFORM
COMBINE
AQUEOUS LAYER
ORGANIC LAYER
DISCARD SOLIDS
ORGANIC PHASE
FILTER THROUGH 47 mm TYPE A GLASS FILTER
DISCARD
COMBINE
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
DESICCATE AND WEIGH TO CONSTANT WEIGHT
EXTRACT WITH 100 ml DI WATER
AQUEOUS PHASE
ORGANIC PHASE
EVAPORATE ON STEAM BATH AND WEIGH TO CONSTANT WEIGHT
FILTER THROUGH A 47 mm TYPE A GLASS FILTER
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
DESICCATE AND WEIGH TO CONSTANT WEIGHT
NOTES:
1) ALL WEIGHTS ARE TO NEAREST 0.01g
2) DESICCATE ALL SAMPLES FOR 24 HOURS PRIOR TO WEIGHING

Figure A-3. Sample Analysis Scheme for Particulate Sampling Train

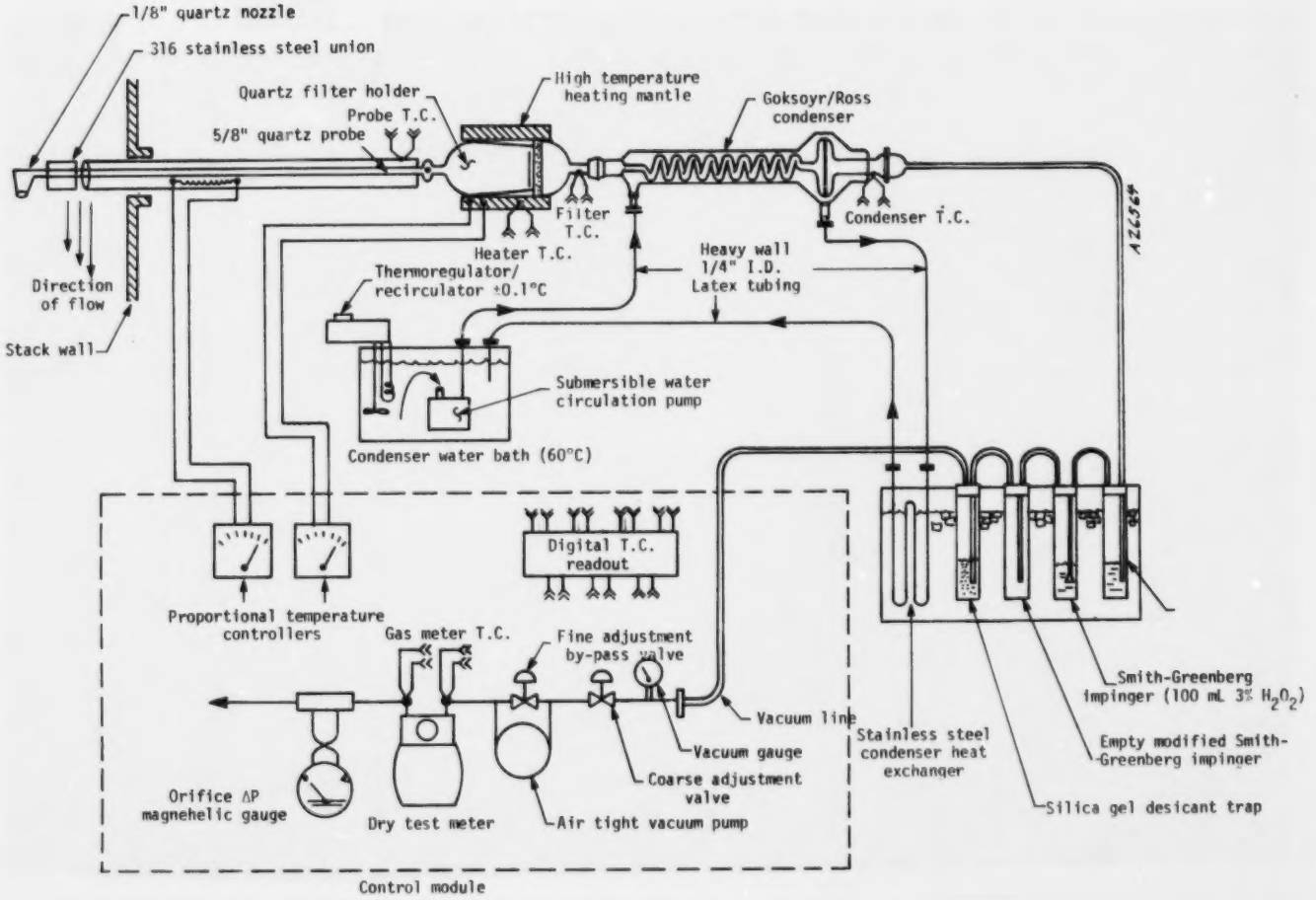


Figure A-4. Controlled Condensation System

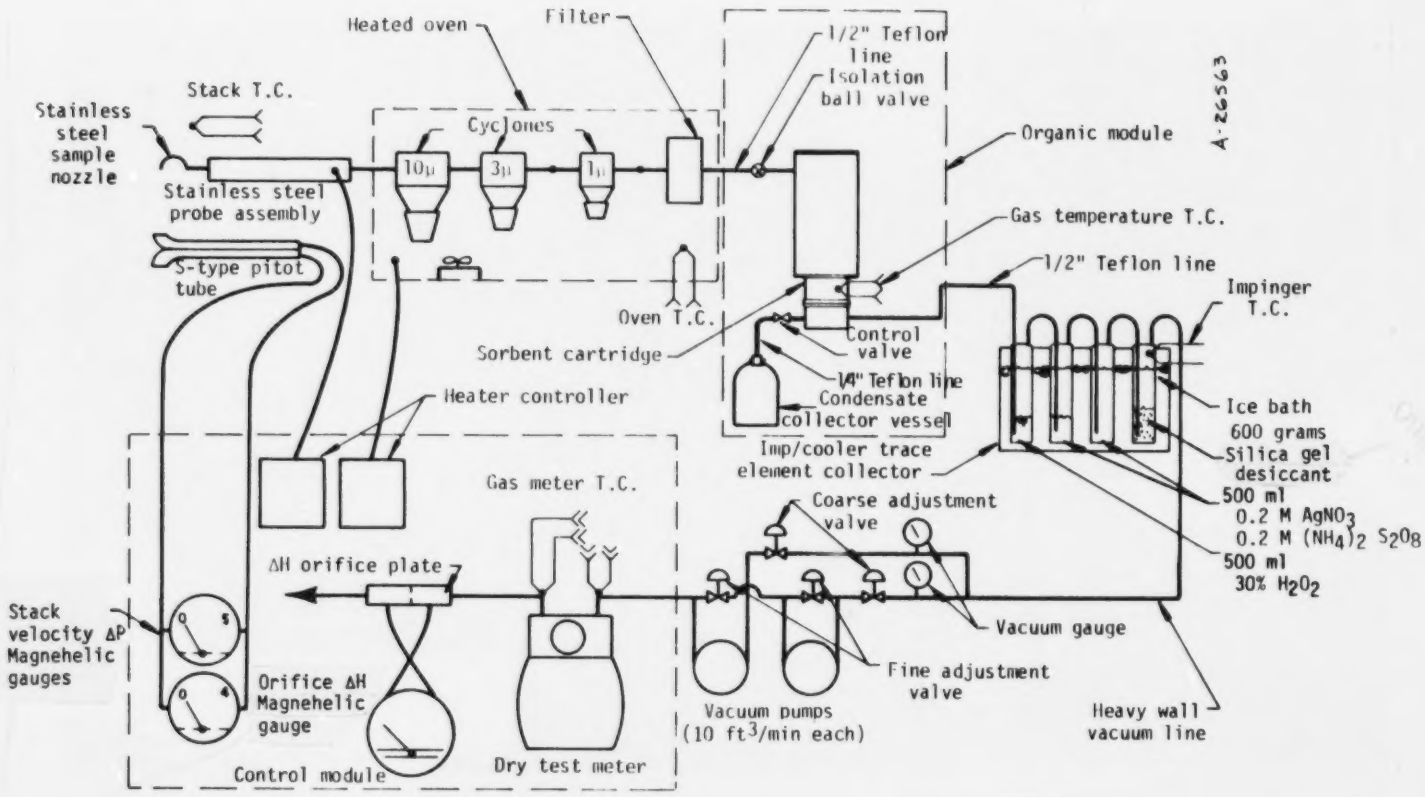


Figure A-5. Schematic of SASS Train

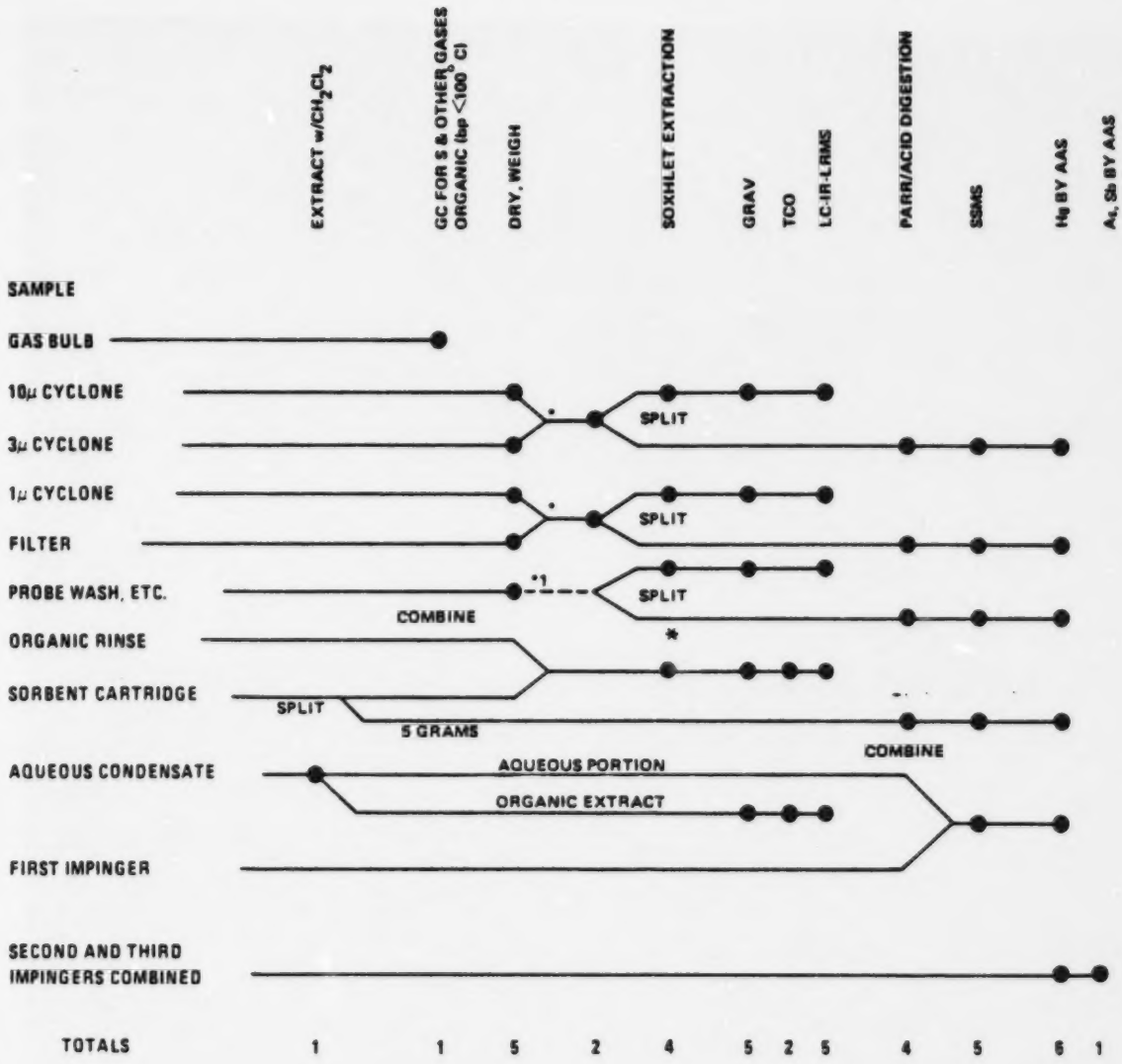
- Particulate cyclones (not used in these tests) heated in the oven with the filter to 230°C (450°F)
- The addition of a gas cooler and organic sampling module
- The addition of necessary vacuum pumps

Schematics outlining the sampling and analytical procedures used with the SASS equipment are presented in figures A-6 and A-7.

Inorganic analyses of solid and liquid samples from the SASS train were performed with spark source mass spectroscopy (SSMS) for most of the trace elements. Atomic absorption spectroscopy (AAS) was used for analyses of mercury (Hg), antimony (Sb) and arsenic (As).

Quantitative information on total organic emissions was obtained by gas chromatography for total chromatographable organics (TCO) and by gravimetry (GRAV) of methylene chloride extracts of solid samples and samples collected in the sorbent module (XAD-2) and condensate trap. Infrared spectroscopy (IR) and GC/MS were used for identification of organic functional groups and polycyclic organic matter (POM) and other organic species in solid and liquid extract SASS samples. Liquid chromatography of extract samples was not performed in this test program because the samples contained less than 15 mg of total organics. Direct insertion probe low resolution mass spectroscopy (LRMS) of the XAD-2 resin extracts was performed to identify and semiquantify organic categories present in extract samples. Figure A-8 illustrates the organic analysis methodology used.

Passivation of the SASS train with 15 percent by volume HNO_3 solution was performed prior to equipment preparation and sampling to produce biologically inert surfaces. Detailed descriptions of equipment preparation, sampling procedures, and sample recovery are discussed in reference A-3 and will not be repeated here.



* If required, sample should be set aside for biological analysis at this point.

[1] This step is required to define the total mass of particulate catch. If the sample exceeds 10% of the total cyclone and filter sample weight, proceed to analysis. If the sample is less than 10% of the catch, hold in reserve.

Figure A-6. Flue Gas Analysis Requirement of SASS Samples

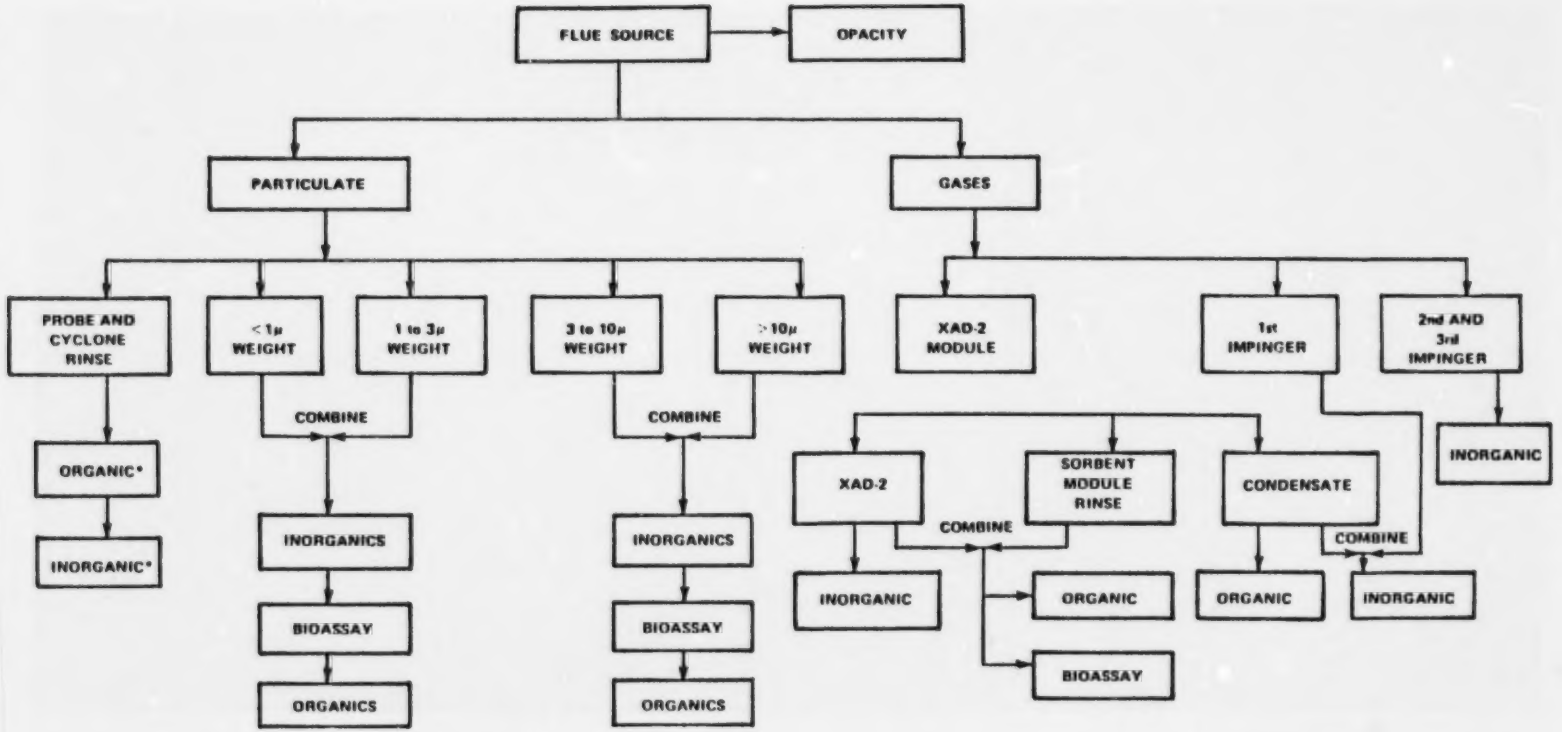


Figure A-7. Exhaust Gas Analysis Protocol

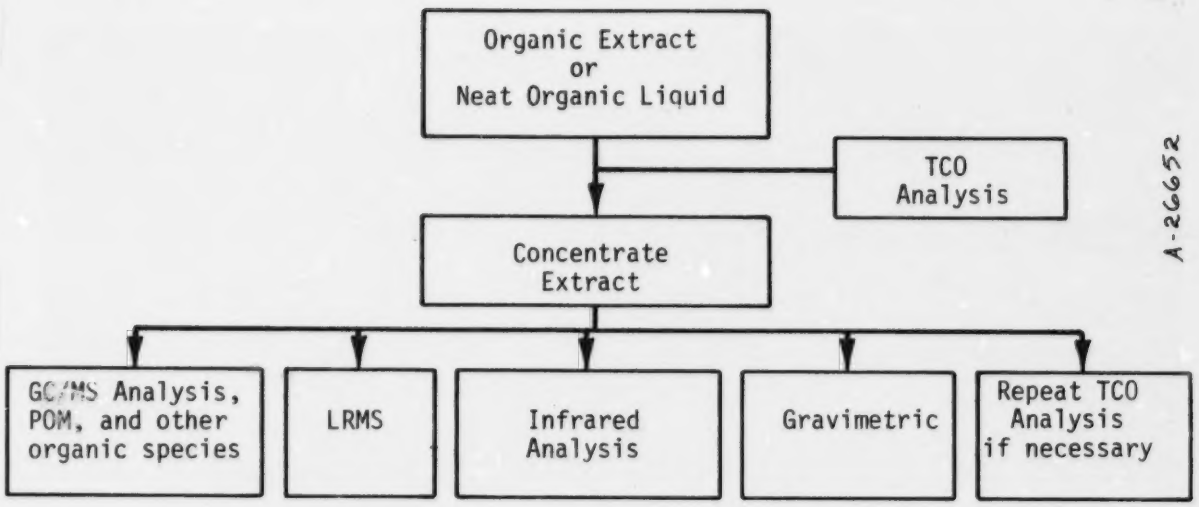


Figure A-8. Organic Analysis Methodology

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A.5 C_1-C_6 HYDROCARBON SAMPLING AND ANALYSIS

Samples of flue gas for C_1-C_6 hydrocarbon analysis were collected using a grab sampling procedure. Flue gas was extracted from the stack at an average velocity point that corresponded with the average velocity point selected for SASS sampling. Samples for hydrocarbon analysis were collected using the apparatus diagramed in figure A-9. The equipment consisted of a nonheated 0.63 cm (0.25-in.) (o.d.), stainless-steel probe fitted with an 0.7 μm-sintered, stainless-steel filter attached to the probe inlet. The outlet of the sampling probe was directly attached to the inlet of a Thomas, Teflon-lined, diaphragm vacuum pump. A 500-cm^3, stainless-steel, heated sampling cylinder placed on the outlet of the pump was used to collect this sample under pressure.

Sampling cylinder construction consisted of specially wrapping each assembly with a 1.8m (6-ft), heavily insulated, 576-watt, heat tape powered by a percentage voltage controller. A type K (Alumel/Chromel) thermocouple implanted on the metal surface of the sampling cylinder was used to monitor the cylinder temperature during operation. To ensure even and efficient heating of the sample cylinder each unit was covered with approximately 1.9-cm (0.75-in.) of ceramic fiber insulation. Figure A-10 presents a schematic of the sampling cylinder construction details.

Prior to flue gas sampling, the sampling cylinders were preconditioned by heating each unit to approximately 150°C (300°F) and purging with zero air (grade 0.1) for 10 min. To extract a flue gas sample the assembled apparatus was positioned and allowed to preheat to the desired sampling temperature of 120° to 150°C (250° to 300°F). Once up to temperature the diaphragm pump was started and the sampling cylinder was alternately pressurized and vented with flue gas to purge the system. Usually 8 to 10 purge cycles were performed with

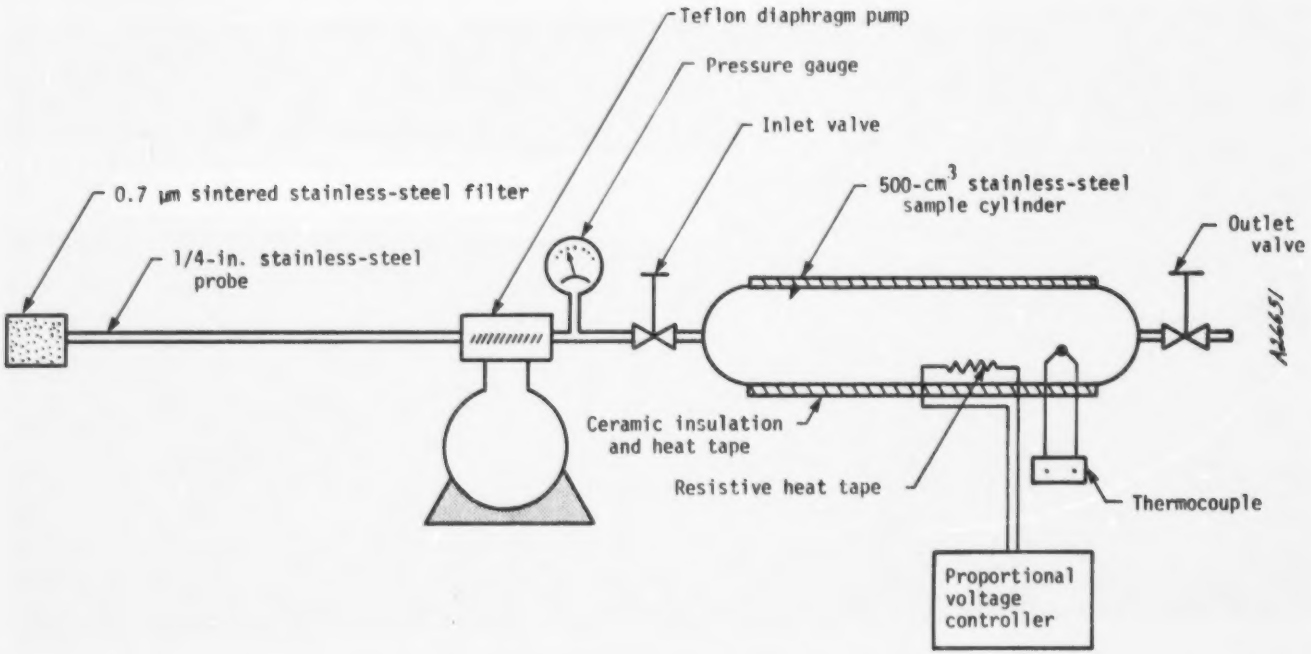

Figure A-9. C_1-C_6 Hydrocarbon Sampling System

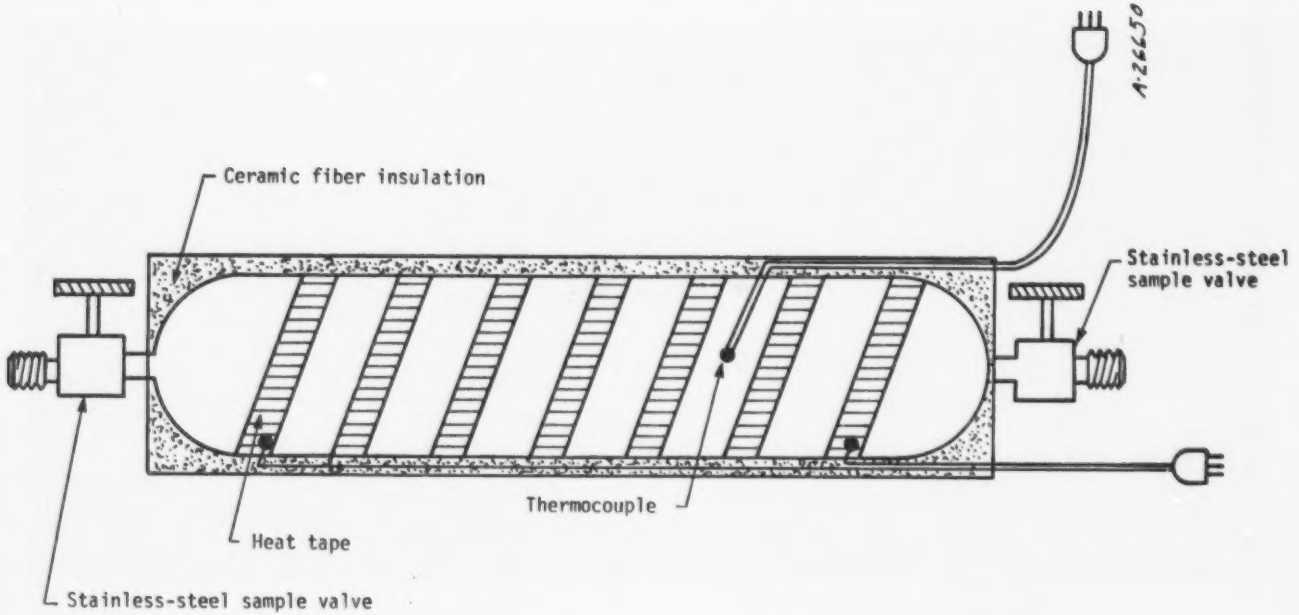

Figure A-10. Schematic of Sampling Cylinder Construction

the last one being retained for analysis. Final pressure in the sampling cylinder was typically 207 to 345 kPa (30 to 50 psia).

Sample analysis was conducted onsite using a Varian, Model 3700, gas chromatograph. This unit is equipped with a flame ionization detector (FID) automatic injection loop, and automatic linear temperature programming. Table A-2 details the instrument specifications. The gas chromatograph output was recorded using a Hewlett-Packard Model 3390A reporting integrator.

All samples and calibration standards were analyzed using repeated injections via the automatic 2-cm^3 heated sampling loop. Separation of C_1-C_6 hydrocarbon components was done on a 1.8m x 0.32 cm x 0.63 cm (6 ft x 1/8 in. x 1/4 in.) (o.d.) silanized stainless-steel column packed with 60/80 mesh Poropak Q (Super Q) using an isothermal program at 120°C. Table A-3 presents a summary of the GC operating condition used for the field analysis.

A summary of C_1-C_6 hydrocarbon analysis conducted on selected samples, sample blanks, and calibration standards may be found in volume II of this report. Calibration standards consisting of a mixture of C_1-C_6 parafinic hydrocarbons (15 ppm each) in nitrogen were analyzed at the beginning and end of each sample day. Blank samples of zero air were also analyzed in order to quantify any sample apparatus equipment interference.

A.6 N_2O EMISSIONS

The stack gas grab samples were extracted into stainless steel cylinders for laboratory analysis for N_2O. For analysis each sample cylinder was externally heated to 120°C (250°F), then a 1-ml sample was withdrawn with a gas-tight syringe for injection into a gas chromatograph. The analytical equipment consisted of a Varian 3700 gas chromatograph equippped with a ^{63}Ni electron capture detector and a 3.65-m (12-ft) stainless-steel column packed

with Poropak Super Q, 80/100 mesh. The injector temperature was kept at 80°C, the detector at 350°C, and the column temperature at 33°C. Elution time for N_2O was approximately 5 min, with a flowrate of 20 ml/min of nitrogen.

Table A-2. Gas Chromatograph Specifications

Varian Model 3700 Gas Chromatograph	
Sensitivity	1×10^{-12} A/mV at attenuation 1 and range 10^{-12} A/mV
Zero range	-10^{-11} to 10^{-9} A (reversible with internal switch)
Noise (inputs capped)	5×10^{-15} A; 0.5 μV peak to peak
Time constant	220 ms on all ranges (approximate 1s response to 99 percent of peak)
Gas required	Carrier gas (helium), combustion air, fuel gas (hydrogen)

Table A-3. Summary of GC Operating Conditions

Injector temperature	120°C
Column temperature	120°C
Detector temperature	250°C
Temperature program	Isothermal (120°C)
Carrier gas	Helium (grade 5.0)
Fuel gas	Hydrogen (grade 5) 276 kPa (40 psi)
Combustion air	Zero air (grade 0.1) 414 kPa (60 psi)

REFERENCES FOR APPENDIX A

A-1. Tidona, R. J., "NO_x Emissions Assessment: Gaseous Emissions From a Refinery Process Heater in Baseline and Low NO_x Configurations," KVB, Inc., Irvine, CA, KVB11 47800-1284, prepared for Acurex Corporation, July 1981.

A-2. Maddalone, R. and N. Gainer, "Process Measurement Procedures: H_2SO_4 Emissions," EPA-600/7-79-156, NTIS PB 80-115959, July 1979.

A-3. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)," EPA-600/7-78-201, NTIS PB 293795, October 1978.

APPENDIX B

TRACE ELEMENT CONCENTRATIONS AND MASS BALANCES

Symbols appearing in the tables:

DSCM	Dry standard cubic meter at 1 atm and 20°C
MCG	Microgram
PPM	Part per million by weight
SEC	Second
ng/J	Nanogram per Joule
<	Less than
>	Greater than
N	Element not analyzed
U	Unable to determine

Trace elements having concentrations less than the detectable limit or having a blank value greater than the sample value were given an arbitrary concentration of zero. Values in the form $A < x < B$ were determined by letting elements reported as less than some concentration be represented by a concentration of zero for the low value and the reported concentration as the high value.

Detectability limits for the various samples were the following:

- Filter — <0.1 μg/g
- XAD-2 — <0.1 μg/g
- Impinger and organic module concentrate — <0.001 μg/ml
- Fuel Oil — <0.1 μg/g

	Baseline	Low NO_x
FUEL IN		
Gas		
m^3/s	0.118	0.118
MW	8.32	8.10
Oil		
g/s	109	109
MW	4.74	4.75
EXHAUST GAS OUT		
DSCM collected by SASS	27.568	27.702
DSCM/s	3.519	3.288
Molecular weight dry	30.01	30.01
Moisture, percent	15.9	16.5
O_2, percent dry	4.0	3.3

Standard conditions: 20°C (68°F) and 1 atm. One molecular weight of an ideal gas occupies 24.04 ℓ at standard conditions.

PPM ELEMENT	FOSCO BASELINE PPM FUEL OIL	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
URANIUM	<.500E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
THORIUM	<.400E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
LEAD	.200E+00	.613E-01	.0 E+00	.0 E+00	N.0 E+00
MERCURY	N.0 E+00	<.453E+00	<.106E+00	<.800E-03	<.900E-03
GOLD	.0 E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
PLATINUM	.200E+01	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
HAFNIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
CERIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
LANTHANUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
BARIUM	.200E+01	.133E+00	.100E+01	.210E-01	N.0 E+00
CESIUM	.0 E+00	.0 E+00	<.100E+00	.200E-02	N.0 E+00
IODINE	.100E+00	.267E-02	.0 E+00	.300E-02	N.0 E+00
TELLURIUM	.0 E+00	.267E-02	.0 E+00	.0 E+00	N.0 E+00
ANTIMONY	.0 E+00	N.0 E+00	N.0 E+00	N.0 E+00	<.130E-01
TIN	.0 E+00	<.267E-02	.0 E+00	.0 E+00	N.0 E+00
CADMIUM	.0 E+00	.267E-02	.0 E+00	.0 E+00	N.0 E+00
SILVER	.0 E+00	.240E-01	.0 E+00	.0 E+00	N.0 E+00
MOLYBDENUM	.0 E+00	.101E+00	.0 E+00	.0 E+00	N.0 E+00
NIOBIUM	.0 E+00	.0 E+00	.0 E+00	.400E-02	N.0 E+00
ZIRCONIUM	.800E+00	.0 E+00	.200E+00	.0 E+00	N.0 E+00
YTTRIUM	.200E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
STRONTIUM	.100E+00	.0 E+00	.300E+01	.100E-02	N.0 E+00
RUBIDIUM	.0 E+00	.0 E+00	<.100E+00	.200E-02	N.0 E+00
BROMINE	.500E+00	.533E-01	.140E+01	.0 E+00	N.0 E+00
SELENIUM	.0 E+00	<.267E-02	.0 E+00	<.800E-02	N.0 E+00
ARSENIC	.0 E+00	N.0 E+00	N.0 E+00	N.0 E+00	<.130E-01
GERMANIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
GALLIUM	.300E+00	.107E-01	.0 E+00	.200E-02	N.0 E+00
ZINC	.900E+01	.117E+01	.200E+01	.300E-01	N.0 E+00
COPPER	.700E+01	.533E-01	.100E+01	.300E-01	N.0 E+00
NICKEL	.800E+01	>.264E+02	.400E+01	.820E-01	N.0 E+00
COBALT	<.100E+00	.259E+00	.0 E+00	.0 E+00	N.0 E+00
IRON	.130E+02	.480E+01	.300E+01	.150E+00	N.0 E+00
MANGANESE	.700E+00	.0 E+00	.100E+00	.900E-02	N.0 E+00
CHROMIUM	.600E+00	.960E-01	.700E+00	.100E-01	N.0 E+00
VANADIUM	.200E+01	.532E+01	.0 E+00	.0 E+00	N.0 E+00
TITANIUM	.600E+01	.0 E+00	.0 E+00	.600E-01	N.0 E+00
SCANDIUM	<.100E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
CALCIUM	.300E+02	U.0 E+00	.0 E+00	.0 E+00	N.0 E+00
POTASSIUM	.800E+02	U.0 E+00	.240E+02	.0 E+00	N.0 E+00
CHLORINE	.200E+01	U.0 E+00	.300E+01	.100E+01	N.0 E+00
SULFUR	>.320E+03	>.373E+01	.400E+01	>.970E+01	N.0 E+00
PHOSPHORUS	.900E+01	.800E-01	.0 E+00	.0 E+00	N.0 E+00
SILICON	.450E+02	U.0 E+00	.400E+01	.830E+01	N.0 E+00

TOSCO BASELINE PPM

PPM ELEMENT	FUEL OIL	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	.150E+02	U.0 E+00	.0 E+00	.0 E+00	N.0 E+00
MAGNESIUM	.100E+02	U.0 E+00	.0 E+00	.100E-01	N.0 E+00
SODIUM	<.100E+00	U.0 E+00	.800E+01	>.980E+01	N.0 E+00
FLUORINE	.200E+00	.0 E+00	.0 E+00	.200E+01	N.0 E+00
BORON	.100E+00	>.107E+02	.0 E+00	.200E-02	N.0 E+00
BERYLLIUM	.0 E+00	<.267E-01	.0 E+00	.0 E+00	N.0 E+00
LITHIUM	.900E+00	.253E+00	.0 E+00	.0 E+00	N.0 E+00

MASS/HEAT INPUT — TCSCC BASELINE NG/J

ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
URANIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
THORIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
LEAD	.249E-05	.0 E+00	.0 E+00	N .0 E+00	.249E-05
MERCURY	< .184E-04	< .134E-03	< .190E-04	< .181E-04	< .190E-03
GOLD	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
PLATINUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
HAFNIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
CERIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
LANTHANUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
BARIUM	.542E-05	.127E-02	.499E-03	N .0 E+00	.177E-02
CESIUM	.0 E+00	< .127E-03	.475E-04	N .0 E+00	.475E-04<XC.174E-03
IODINE	.108E-06	.0 E+00	.713E-04	N .0 E+00	.714E-04
TELLURIUM	.108E-06	.0 E+00	.0 E+00	N .0 E+00	.108E-06
ANTIMONY	N .0 E+00	N .0 E+00	N .0 E+00	< .261E-03	< .261E-03
TIN	< .108E-06	.0 E+00	.0 E+00	N .0 E+00	< .108E-06
CADMIUM	.108E-06	.0 E+00	.0 E+00	N .0 E+00	.108E-06
SILVER	.976E-06	.0 E+00	.0 E+00	N .0 E+00	.976E-06
MOLYBDENUM	.412E-05	.0 E+00	.0 E+00	N .0 E+00	.412E-05
NIOBIUM	.0 E+00	.0 E+00	.951E-04	N .0 E+00	.951E-04
ZIRCONIUM	.0 E+00	.253E-03	.0 E+00	N .0 E+00	.253E-03
YTTRIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
STRONTIUM	.0 E+00	.380E-02	.238E-04	N .0 E+00	.382E-02
RUBIDIUM	.0 E+00	< .127E-03	.475E-04	N .0 E+00	.475E-04<XC.174E-03
BROMINE	.217E-05	.177E-02	.0 E+00	N .0 E+00	.178E-02
SELENIUM	< .108E-06	.0 E+00	< .190E-03	N .0 E+00	< .190E-03
ARSENIC	N .0 E+00	N .0 E+00	N .0 E+00	< .261E-03	< .261E-03
GERMANIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
GALLIUM	.434E-06	.0 E+00	.475E-04	N .0 E+00	.480E-04
ZINC	.477E-04	.253E-02	.713E-03	N .0 E+00	.329E-02
COPPER	.217E-05	.127E-02	.713E-03	N .0 E+00	.198E-02
NICKEL	> .107E-02	.507E-02	.195E-02	N .0 E+00	> .809E-02
COBALT	.105E-04	.0 E+00	.0 E+00	N .0 E+00	.105E-04
IRON	.195E-03	.380E-02	.357E-02	N .0 E+00	.756E-02
MANGANESE	.0 E+00	.127E-03	.214E-03	N .0 E+00	.341E-03
CHROMIUM	.390E-05	.887E-03	.238E-03	N .0 E+00	.113E-02
VANADIUM	.217E-03	.0 E+00	.0 E+00	N .0 E+00	.217E-03
TITANIUM	.0 E+00	.0 E+00	.143E-02	N .0 E+00	.143E-02
SCANDIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
CALCIUM	U .0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
POTASSIUM	U .0 E+00	.304E-01	.0 E+00	N .0 E+00	.304E-01
CHLORINE	U .0 E+00	.380E-02	.238E-01	N .0 E+00	.276E-01
SULFUR	> .152E-03	.507E-02	> .231E+00	N .0 E+00	> .236E+00
PHOSPHORUS	.325E-05	.0 E+00	.0 E+00	N .0 E+00	.325E-05
SILICON	U .0 E+00	.507E-02	.197E+00	N .0 E+00	.202E+00

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MASS/HEAT INPUT

TCSC)
BASELINE
NG/J

ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
ALUMINUM	U .0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
MAGNESIUM	U .0 E+00	.0 E+00	.238E-03	N .0 E+00	.238E-03
SODIUM	U .0 E+00	.101E-01	> .233E+00	N .0 E+00	> .243E+00
FLUORINE	.0 E+00	.0 E+00	.475E-01	N .0 E+00	.475E-01
BORON	> .434E-03	.0 E+00	.475E-04	N .0 E+00	> .481E-03
BERYLLIUM	< .108E-05	.0 E+00	.0 E+00	N .0 E+00	< .108E-05
LITHIUM	.103E-04	.0 E+00	.0 E+00	N .0 E+00	.103E-04

TOSCO
BASELINE
NG/J

MASS / HEAT INPUT

ELEMENT	FUEL OIL	HEATER OUTLET
URANIUM	< .115E-01	.0 E+00
THORIUM	< .919E-02	.0 E+00
LEAD	.459E-02	.249E-05
MERCURY	N .0 E+00	< .190E-03
GOLD	.0 E+00	.0 E+00
PLATINUM	.459E-01	.0 E+00
HAFNIUM	.0 E+00	.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00
CERIUM	.0 E+00	.0 E+00
LANTHANUM	.0 E+00	.0 E+00
BARIUM	.459E-01	.177E-02
CESIUM	.0 E+00	.475E-04<X<.174E-03
IODINE	.230E-02	.714E-04
TELLURIUM	.0 E+00	.108E-06
ANTIMONY	.0 E+00	< .261E-03
TIN	.0 E+00	< .108E-06
CADMIUM	.0 E+00	.108E-06
SILVER	.0 E+00	.976E-06
MOLYBDENUM	.0 E+00	.412E-05
NIOBIUM	.0 E+00	.951E-04
ZIRCONIUM	.184E-01	.253E-03
YTTRIUM	.459E-02	.0 E+00
STRONTIUM	.230E-02	.382E-02
RUBIDIUM	.0 E+00	.475E-04<X<.174E-03
BROMINE	.115E-01	.178E-02
SELENIUM	.0 E+00	< .190E-03
ARSENIC	.0 E+00	< .261E-03
GERMANIUM	.0 E+00	.0 E+00
GALLIUM	.689E-02	.480E-04
ZINC	.207E+00	.329E-02
COPPER	.161E+00	.198E-02
NICKEL	.184E+00	> .809E-02
COBALT	< .230E-02	.105E-04
IRON	.299E+00	.756E-02
MANGANESE	.161E-01	.341E-03
CHROMIUM	.138E-01	.113E-02
VANADIUM	.459E-01	.217E-03
TITANIUM	.138E+00	.143E-02
SCANDIUM	< .230E-02	.0 E+00
CALCIUM	.689E+00	.0 E+00
POTASSIUM	.184E+01	.304E-01
CHLORINE	.459E-01	.276E-01
SULFUR	> .735E+01	> .236E+00
PHOSPHORUS	.207E+00	.325E-05
SILICON	.103E+01	.202E+00

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MASS / HEAT INPUT (CSC) BASELINE NG/J

ELEMENT	FUEL OIL	HEATER OUTLET
ALUMINUM	.344E+00	.0 E+00
MAGNESIUM	.23UE+00	.238E-03
SODIUM	< .23UE-02	> .243E+00
FLUORINE	.459E-02	.475E-01
BORON	.23UE-02	> .481E-03
BERYLLIUM	.0 E+00	< .108E-05
LITHIUM	.207E-01	.103E-04

TGSCO BASELINE

CONCENTRATION MCG/DSCM

ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
URANIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
THORIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
LEAD	.928E-02	.0 E+00	.0 E+00	N .0 E+00	.928E-02
MERCURY	< .686E-01	< .500E+00	< .708E-01	< .672E-01	< .706E+00
GOLD	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
PLATINUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
HAFNIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
CERIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
LANTHANUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
BARIUM	.202E-01	.471E+01	.186E+01	N .0 E+00	.659E+01
CESIUM	.0 E+00	< .471E+00	.177E+00	N .0 E+00	.177E+00<X<.648E+00
IODINE	.404E-03	.0 E+00	.265E+00	N .0 E+00	.266E+00
TELLURIUM	.404E-03	.0 E+00	.0 E+00	N .0 E+00	.404E-03
ANTIMONY	N .0 E+00	N .0 E+00	N .0 E+00	< .971E+00	< .971E+00
TIN	< .404E-03	.0 E+00	.0 E+00	N .0 E+00	< .404E-03
CADMIUM	.404E-03	.0 E+00	.0 E+00	N .0 E+00	.404E-03
SILVER	.363E-02	.0 E+00	.0 E+00	N .0 E+00	.363E-02
MOLYBDENUM	.153E-01	.0 E+00	.0 E+00	N .0 E+00	.153E-01
NIOBIUM	.0 E+00	.0 E+00	.354E+00	N .0 E+00	.354E+00
ZIRCONIUM	.0 E+00	.943E+00	.0 E+00	N .0 E+00	.943E+00
YTTRIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
STRONTIUM	.0 E+00	.141E+02	.885E-01	N .0 E+00	.142E+02
RUBIDIUM	.0 E+00	< .471E+00	.177E+00	N .0 E+00	.177E+00<X<.648E+00
BROMINE	.807E-02	.660E+01	.0 E+00	N .0 E+00	.661E+01
SELENIUM	< .404E-03	.0 E+00	< .708E+00	N .0 E+00	< .708E+00
ARSENIC	N .0 E+00	N .0 E+00	N .0 E+00	< .971E+00	< .971E+00
GERMANIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
GALLIUM	.161E-02	.0 E+00	.177E+00	N .0 E+00	.179E+00
ZINC	.178E+00	.943E+01	.265E+01	N .0 E+00	.123E+02
COPPER	.807E-02	.471E+01	.265E+01	N .0 E+00	.738E+01
NICKEL	> .400E+01	.189E+02	.726E+01	N .0 E+00	> .301E+02
COBALT	.392E-01	.0 E+00	.0 E+00	N .0 E+00	.392E-01
IRON	.727E+00	.141E+02	.133E+02	N .0 E+00	.281E+02
MANGANESE	.0 E+00	.471E+00	.796E+00	N .0 E+00	.127E+01
CHROMIUM	.145E-01	.330E+01	.885E+00	N .0 E+00	.420E+01
VANADIUM	.806E+00	.0 E+00	.0 E+00	N .0 E+00	.806E+00
TITANIUM	.0 E+00	.0 E+00	.531E+01	N .0 E+00	.531E+01
SCANDIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
CALCIUM	U .0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
POTASSIUM	U .0 E+00	.113E+03	.0 E+00	N .0 E+00	.113E+03
CHLORINE	U .0 E+00	.141E+02	.885E+02	N .0 E+00	.103E+03
SULFUR	> .565E+00	.189E+02	> .858E+03	N .0 E+00	> .878E+03
PHOSPHORUS	.121E-01	.0 E+00	.0 E+00	N .0 E+00	.121E-01
SILICON	U .0 E+00	.189E+02	.734E+03	N .0 E+00	.753E+03

TGSCC

CONCENTRATION BASELINE MCG/DSCM

ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
ALUMINUM	U .0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
MAGNESIUM	U .0 E+00	.0 E+00	.885E+00	N .0 E+00	.885E+00
SODIUM	U .0 E+00	.377E+02	> .867E+03	N .0 E+00	> .905E+03
FLUORINE	.0 E+00	.0 E+00	.177E+03	N .0 E+00	.177E+03
BORON	> .161E+01	.0 E+00	.177E+00	N .0 E+00	> .179E+01
BERYLLIUM	< .404E-02	.0 E+00	.0 E+00	N .0 E+00	< .404E-02
LITHIUM	.383E-01	.0 E+00	.0 E+00	N .0 E+00	.383E-01

TOSCO
BASELINE
MCG/SEC

MASS/TIME ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
URANIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
THORIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
LEAD	.327E-01	.0 E+00	.0 E+00	N .0 E+00	.327E-01
MERCURY	< .242E+00	< .176E+01	< .249E+00	< .237E+00	< .249E+01
GOLD	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
PLATINUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
HAFNIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
CERIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
LANTHANUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
BARIUM	.710E-01	.166E+02	.656E+01	N .0 E+00	.232E+02
CESIUM	.0 E+00	< .166E+01	.623E+00	N .0 E+00	.623E+00<X<.228E+01
IODINE	.142E-02	.0 E+00	.934E+00	N .0 E+00	.936E+00
TELLURIUM	.142E-02	.0 E+00	.0 E+00	N .0 E+00	.142E-02
ANTIMONY	N .0 E+00	N .0 E+00	N .0 E+00	< .342E+01	< .342E+01
TIN	< .142E-02	.0 E+00	.0 E+00	N .0 E+00	< .142E-02
CADMIUM	.142E-02	.0 E+00	.0 E+00	N .0 E+00	.142E-02
SILVER	.128E-01	.0 E+00	.0 E+00	N .0 E+00	.128E-01
MOLYBDENUM	.540E-01	.0 E+00	.0 E+00	N .0 E+00	.540E-01
NIOBIUM	.0 E+00	.0 E+00	.125E+01	N .0 E+00	.125E+01
ZIRCONIUM	.0 E+00	.332E+01	.0 E+00	N .0 E+00	.332E+01
YITRIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
STRONTIUM	.0 E+00	.498E+02	.311E+00	N .0 E+00	.501E+02
RUBIDIUM	.0 E+00	< .166E+01	.623E+00	N .0 E+00	.623E+00<X<.228E+01
BROMINE	.284E-01	.232E+02	.0 E+00	N .0 E+00	.233E+02
SELENIUM	< .142E-02	.0 E+00	< .249E+01	N .0 E+00	< .249E+01
ARSENIC	N .0 E+00	N .0 E+00	N .0 E+00	< .342E+01	< .342E+01
GERMANIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
GALLIUM	.568E-02	.0 E+00	.623E+00	N .0 E+00	.629E+00
ZINC	.625E+00	.332E+02	.934E+01	N .0 E+00	.432E+02
COPPER	.284E-01	.166E+02	.934E+01	N .0 E+00	.260E+02
NICKEL	> .141E+02	.664E+02	.255E+02	N .0 E+00	> .106E+03
COBALT	.138E+00	.0 E+00	.0 E+00	N .0 E+00	.138E+00
IRON	.256E+01	.498E+02	.467E+02	N .0 E+00	.991E+02
MANGANESE	.0 E+00	.166E+01	.280E+01	N .0 E+00	.446E+01
CHROMIUM	.511E-01	.116E+02	.311E+01	N .0 E+00	.148E+02
VANADIUM	.284E+01	.0 E+00	.0 E+00	N .0 E+00	.284E+01
TITANIUM	.0 E+00	.0 E+00	.187E+02	N .0 E+00	.187E+02
SCANDIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
CALCIUM	U .0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
POTASSIUM	U .0 E+00	.398E+03	.0 E+00	N .0 E+00	.398E+03
CHLORINE	U .0 E+00	.498E+02	.311E+03	N .0 E+00	.361E+03
SULFUR	> .199E+01	.664E+02	> .302E+04	N .0 E+00	> .309E+04
PHOSPHORUS	.426E-01	.0 E+00	.0 E+00	N .0 E+00	.426E-01
SILICON	U .0 E+00	.664E+02	.259E+04	N .0 E+00	.265E+04

TCSCC BASELINE MCG/SEC

MASS/TIME ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
ALUMINUM	U .0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
MAGNESIUM	U .0 E+00	.0 E+00	.311E+01	N .0 E+00	.311E+01
SODIUM	U .0 E+00	.133E+03	> .305E+04	N .0 E+00	> .319E+04
FLUORINE	.0 E+00	.0 E+00	.622E+03	N .0 E+00	.622E+03
BORON	> .568E+01	.0 E+00	.623E+00	N .0 E+00	> .631E+01
BERYLLIUM	< .142E-01	.0 E+00	.0 E+00	N .0 E+00	< .142E-01
LITHIUM	.135E+00	.0 E+00	.0 E+00	N .0 E+00	.135E+00

TOSCO

MASS/ TIME — BASELINE — MCG/SEC

ELEMENT	FUEL OIL	HEATER OUTLET
URANIUM	< .547E+02	.0 E+00
THORIUM	< .438E+02	.0 E+00
LEAD	.219E+02	.327E-01
MERCURY	N .0 E+00	< .249E+01
GOLD	.0 E+00	.0 E+00
PLATINUM	.219E+03	.0 E+00
HAFNIUM	.0 E+00	.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00
CERIUM	.0 E+00	.0 E+00
LANTHANUM	.0 E+00	.0 E+00
BARIUM	.219E+03	.232E+02
CESIUM	.0 E+00	.623E+00<X<.228E+01
IODINE	.109E+02	.936E+00
TELLURIUM	.0 E+00	.142E-02
ANTIMONY	.0 E+00	< .342E+01
TIN	.0 E+00	< .142E-02
CADMIUM	.0 E+00	.142E-02
SILVER	.0 E+00	.128E-01
MOLYBDENUM	.0 E+00	.540E-01
NIOBIUM	.0 E+00	.125E+01
ZIRCONIUM	.875E+02	.332E+01
YTTRIUM	.219E+02	.0 E+00
STRONTIUM	.109E+02	.501E+02
RUBIDIUM	.0 E+00	.623E+00<X<.228E+01
BROMINE	.547E+02	.233E+02
SELENIUM	.0 E+00	< .249E+01
ARSENIC	.0 E+00	< .342E+01
GERMANIUM	.0 E+00	.0 E+00
GALLIUM	.328E+02	.629E+00
ZINC	.985E+03	.432E+02
COPPER	.766E+03	.260E+02
NICKEL	.875E+03	> .106E+03
COBALT	< .109E+02	.138E+00
IRON	.142E+04	.991E+02
MANGANESE	.766E+02	.446E+01
CHROMIUM	.656E+02	.148E+02
VANADIUM	.219E+03	.284E+01
TITANIUM	.656E+03	.187E+02
SCANDIUM	< .109E+02	.0 E+00
CALCIUM	.328E+04	.0 E+00
POTASSIUM	.875E+04	.398E+03
CHLORINE	.219E+03	.361E+03
SULFUR	> .350E+05	> .309E+04
PHOSPHORUS	.985E+03	.426E-01
SILICON	.492E+04	.265E+04

TOSCO
BASELINE

MASS/ TIME MCG/SEC

ELEMENT	FUEL OIL	HEATER OUTLET
ALUMINUM	.164E+04	.0 E+00
MAGNESIUM	.109E+04	.311E+01
SODIUM	< .109E+02	> .319E+04
FLUORINE	.219E+02	.622E+03
BORON	.109E+02	> .631E+01
BERYLLIUM	.0 E+00	< .142E-01
LITHIUM	.985E+02	.135E+00

TOSCO
BASELINE
NG/SEC
HEATER MASS BALANCE

IN : FUEL OIL OUT : HEATER EXHAUST GAS

ELEMENT	TOTAL IN	TOTAL OUT	MASS BALANCE(OUT/IN)
URANIUM	X<.547E+02		.0 E+00
THORIUM	X<.438E+02		.0 E+00
LEAD	.219E+02	.327E-01	.149E-02
MERCURY		X<.249E+01	*
GOLD			*
PLATINUM	.219E+03		.0 E+00
HAFNIUM			*
PRASEODYMIUM			*
CERIUM			*
LANTHANUM			*
BARIUM	.219E+03	.232E+02	.106E+00
CESIUM		.623E+00<X<.228E+01	*
IODINE	.109E+02	.936E+00	.855E-01
TELLURIUM		.142E-02	*
ANTIMONY		X<.342E+01	*
TIN		X<.142E-02	*
CADMIUM		.142E-02	*
SILVER		.128E-01	*
MOLYBDENUM		.540E-01	*
NIOBIUM		.125E+01	*
ZIRCONIUM	.875E+02	.332E+01	.379E-01
YTTRIUM	.219E+02		.0 E+00
STRONTIUM	.109E+02	.501E+02	.458E+01
RUBIDIUM		.623E+00<X<.228E+01	*
BROMINE	.547E+02	.233E+02	.425E+00
SELENIUM		X<.249E+01	*
ARSENIC		X<.342E+01	*
GERMANIUM			*
GALLIUM	.328E+02	.629E+00	.192E-01
ZINC	.985E+03	.432E+02	.438E-01
COPPER	.766E+03	.260E+02	.339E-01
NICKEL	.875E+03	.106E+03 <X	.121E+00 <X
COBALT	X<.109E+02	.138E+00	.126E-01 <X
IRON	.142E+04	.991E+02	.697E-01
MANGANESE	.766E+02	.446E+01	.583E-01
CHROMIUM	.656E+02	.148E+02	.225E+00
VANADIUM	.219E+03	.284E+01	.130E-01
TITANIUM	.656E+03	.187E+02	.285E-01
SCANDIUM	X<.109E+02		.0 E+00
CALCIUM	.328E+04		.0 E+00
POTASSIUM	.875E+04	.398E+03	.455E-01
CHLORINE	.219E+03	.361E+03	.165E+01
SULFUR	.35CE+05 <X	.309E+04 <X	*
PHOSPHORUS	.985E+03	.426E-01	.433E-04
SILICON	.492E+04	.265E+04	.539E+00

TGSCO
BASELINE
MCG/SEC
HEATER MASS BALANCE

IN : FUEL OIL OUT : HEATER EXHAUST GAS

ELEMENT	TOTAL IN	TOTAL OUT	MASS BALANCE(OUT/IN)
ALUMINUM	.164E+04	.311E+01	.0 E+00
MAGNESIUM	.109E+04	.319E+04 <X	.285E-02
SODIUM	X<.109E+02	.622E+03	.291E+03 <X
FLUORINE	.219E+02	.631E+01 <X	.284E+02
BORON	.109E+02	X<.142E-01	.576E+00 <X
BERYLLIUM		.135E+00	*
LITHIUM	.985E+02		.137E-02

TOSCO
LOW NOX

PPM ELEMENT	FUEL OIL	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
URANIUM	<.800E+00	.752E-02	.0 E+00	.0 E+00	N.0 E+00
THORIUM	<.900E+00	.752E-02	.0 E+00	.0 E+00	.0 E+00
LEAD	.900E+00	.133E+00	.0 E+00	.900E-02	N.0 E+00
MERCURY	N.0 E+00	<.251E+00	<.430E-01	<.700E-04	<.120E-02
GOLD	.0 E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
PLATINUM	.110E+02	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
HAFNIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
CERIUM	.0 E+00	.0 E+00	.0 E+00	.900E-02	N.0 E+00
LANTHANUM	.0 E+00	.0 E+00	.0 E+00	.200E-01	N.0 E+00
BARIUM	.100E+01	.401E+00	.200E+01	.400E-01	N.0 E+00
CESIUM	.0 E+00	.0 E+00	<.100E+00	.0 E+00	N.0 E+00
IODINE	.0 E+00	.0 E+00	.200E+00	.0 E+00	N.0 E+00
TELLURIUM	.0 E+00	<.251E-02	.0 E+00	<.400E-02	N.0 E+00
ANTIMONY	.0 E+00	N.0 E+00	N.0 E+00	N.0 E+00	<.170E-01
TIN	.0 E+00	.251E-02	.0 E+00	.0 E+00	N.0 E+00
CADMIUM	.0 E+00	.251E-02	.100E+00	.0 E+00	N.0 E+00
SILVER	.0 E+00	.248E+00	.0 E+00	.500E-01	N.0 E+00
MOLYBDENUM	.0 E+00	.221E+00	.600E+00	.100E-02	N.0 E+00
NIOBIUM	.0 E+00	.0 E+00	.0 E+00	.200E-01	N.0 E+00
ZIRCONIUM	.0 E+00	.0 E+00	.100E+01	.280E-01	N.0 E+00
YTTRIUM	.0 E+00	.501E-02	.0 E+00	.200E-02	N.0 E+00
STRONTIUM	.500E+00	.0 E+00	.0 E+00	.170E-01	N.0 E+00
RUBIDIUM	.0 E+00	.0 E+00	<.100E+00	<.150E-01	N.0 E+00
BROMINE	.0 E+00	.251E-01	.440E+01	<.200E-01	N.0 E+00
SELENIUM	.0 E+00	.100E-01	.0 E+00	<.200E-01	N.0 E+00
ARSENIC	.0 E+00	N.0 E+00	N.0 E+00	N.0 E+00	<.170E-01
GERMANIUM	.0 E+00	.251E-02	.0 E+00	.0 E+00	N.0 E+00
GALLIUM	.100E+00	.100E-01	.0 E+00	.0 E+00	N.0 E+00
ZINC	.300E+01	.110E+01	.0 E+00	.700E+00	N.0 E+00
COPPER	.600E+01	.201E+00	.600E+01	.180E+00	N.0 E+00
NICKEL	.800E+01	.223E+02	.0 E+00	.190E+00	N.0 E+00
COBALT	<.200E+00	.496E+00	.0 E+00	.0 E+00	N.0 E+00
IRON	.260E+02	.702E+01	.290E+02	.410E+00	N.0 E+00
MANGANESE	.500E+00	.201E+00	.100E+00	.800E-01	N.0 E+00
CHROMIUM	.100E+01	.993E+00	.470E+01	.400E-01	N.0 E+00
VANADIUM	.800E+00	.501E+01	.100E+00	.300E-02	N.0 E+00
TITANIUM	.100E+02	.0 E+00	.0 E+00	.400E-01	N.0 E+00
SCANDIUM	.0 E+00	.0 E+00	.0 E+00	<.100E-02	N.0 E+00
CALCIUM	.160E+02	U.0 E+00	.790E+02	.100E+00	N.0 E+00
POTASSIUM	.660E+02	U.0 E+00	.235E+03	U.0 E+00	N.0 E+00
CHLORINE	.500E+01	U.0 E+00	.140E+02	.0 E+00	N.0 E+00
SULFUR	.330E+02	>.351E+01	.700E+02	>.950E+01	N.0 E+00
PHOSPHORUS	.500E+01	.326E+00	.700E+01	.0 E+00	N.0 E+00
SILICON	.160E+02	U.0 E+00	.165E+03	.0 E+00	N.0 E+00

TOSCO
LCW NOX
PPM

ELEMENT	FUEL OIL	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	.130E+02	U.0 E+00	.170E+02	.0 E+00	N.0 E+00
MAGNESIUM	.120E+02	U.0 E+00	.200E+01	.0 E+00	N.0 E+00
SODIUM	.600E+01	U.0 E+00	>.147E+03	U.0 E+00	N.0 E+00
FLUORINE	.400E+00	.0 E+00	.100E+00	.0 E+00	N.0 E+00
BORON	.100E+01	.0 E+00	.0 E+00	.0 E+00	N.0 E+00
BERYLLIUM	.0 E+00	<.251E-02	.0 E+00	.0 E+00	.0 E+00
LITHIUM	.200E+01	.376E-01	.0 E+00	.0 E+00	N.0 E+00

TESCO
LCM AUX
NO/3

MASS/HEAT INPUT

ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
URANIUM	.302E-06	.0 E+00	.0 E+00	N .0 E+00	.302E-06
THORIUM	.302E-06	.0 E+00	.0 E+00	.0 E+00	.302E-06
LEAD	.534E-05	.0 E+00	.305E-03	N .0 E+00	.310E-03
MERCURY	< .101E-04	< .506E-04	< .237E-05	< .170E-04	< .801E-04
GOLD	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
PLATINUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
HAFNIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
CERIUM	.0 E+00	.0 E+00	.305E-03	N .0 E+00	.305E-03
LANTHANUM	.0 E+00	.0 E+00	.678E-03	N .0 E+00	.678E-03
BARIUM	.161E-04	.236E-02	.136E-02	N .0 E+00	.373E-02
CESIUM	.0 E+00	< .118E-03	.0 E+00	N .0 E+00	< .118E-03
IODINE	.0 E+00	.236E-03	.0 E+00	N .0 E+00	.236E-03
TELLURIUM	< .101E-06	.0 E+00	< .136E-03	N .0 E+00	< .136E-03
ANTIMONY	N .0 E+00	N .0 E+00	N .0 E+00	< .240E-03	< .240E-03
TIN	.101E-06	.0 E+00	.0 E+00	N .0 E+00	.101E-06
CADMIUM	.101E-06	.118E-03	.0 E+00	N .0 E+00	.118E-03
SILVER	.998E-05	.0 E+00	.169E-02	N .0 E+00	.170E-02
MOLYBDENUM	.887E-05	.707E-03	.339E-04	N .0 E+00	.749E-03
NIOBIUM	.0 E+00	.0 E+00	.678E-03	N .0 E+00	.678E-03
ZIRCONIUM	.0 E+00	.118E-02	.949E-03	N .0 E+00	.213E-02
YTTRIUM	.202E-06	.0 E+00	.678E-04	N .0 E+00	.680E-04
STRONTIUM	.0 E+00	.0 E+00	.576E-03	N .0 E+00	.576E-03
RUBIDIUM	.0 E+00	< .118E-03	< .508E-03	N .0 E+00	< .626E-03
BROMINE	.101E-05	.518E-02	< .678E-03	N .0 E+00	.518E-02<X<.586E-02
SELENIUM	.403E-06	.0 E+00	< .678E-03	N .0 E+00	.403E-06<X<.678E-03
ARSENIC	N .0 E+00	N .0 E+00	N .0 E+00	< .240E-03	< .240E-03
GERMANIUM	.101E-06	.0 E+00	.0 E+00	N .0 E+00	.101E-06
GALLIUM	.403E-06	.0 E+00	.0 E+00	N .0 E+00	.403E-06
ZINC	.444E-04	.0 E+00	.237E-01	N .0 E+00	.238E-01
COPPER	.807E-05	.707E-02	.610E-02	N .0 E+00	.132E-01
NICKEL	.897E-03	.0 E+00	.644E-02	N .0 E+00	.733E-02
COBALT	.199E-04	.0 E+00	.0 E+00	N .0 E+00	.199E-04
IRON	.282E-03	.342E-01	.139E-01	N .0 E+00	.483E-01
MANGANESE	.807E-05	.118E-03	.271E-02	N .0 E+00	.284E-02
CHROMIUM	.399E-04	.554E-02	.136E-02	N .0 E+00	.693E-02
VANADIUM	.201E-03	.118E-03	.102E-03	N .0 E+00	.421E-03
TITANIUM	.0 E+00	.0 E+00	.136E-02	N .0 E+00	.136E-02
SCANDIUM	.0 E+00	.0 E+00	< .339E-04	N .0 E+00	< .339E-04
CALCIUM	U .0 E+00	.930E-01	.339E-02	N .0 E+00	.966E-01
POTASSIUM	U .0 E+00	.277E+00	U .0 E+00	N .0 E+00	.277E+00
CHLORINE	U .0 E+00	.165E-01	.0 E+00	N .0 E+00	.165E-01
SULFUR	> .141E-03	.824E-01	> .322E+00	N .0 E+00	> .404E+00
PHOSPHORUS	.131E-06	.824E-02	.0 E+00	N .0 E+00	.826E-02
SILICON	U .0 E+00	.194E+00	.0 E+00	N .0 E+00	.194E+00

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MASS/HEAT INPUT

Test
Low NOx
ng/J

ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
ALUMINUM	U .0 E+00	.200E-01	.0 E+00	N .0 E+00	.200E-01
MAGNESIUM	U .0 E+00	.236E-02	.0 E+00	N .0 E+00	.236E-02
SODIUM	U .0 E+00	> .173E+00	U .0 E+00	N .0 E+00	> .173E+00
FLUORINE	.0 E+00	.118E-03	.0 E+00	N .0 E+00	.118E-03
BORON	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
BERYLLIUM	< .101E-06	.0 E+00	.0 E+00	.0 E+00	< .101E-06
LITHIUM	.151E-05	.0 E+00	.0 E+00	N .0 E+00	.151E-05

MASS/HEAT INPUT		TOSCO LOW NOX KG/J	
ELEMENT	FUEL OIL		HEATER OUTLET
URANIUM	<	.183E-01	.302E-06
THORIUM	<	.206E-01	.302E-06
LEAD		.206E-01	.310E-03
MERCURY	N	.0 E+00	< .801E-04
GOLD		.0 E+00	.0 E+00
PLATINUM		.252E+00	.0 E+00
HAFNIUM		.0 E+00	.0 E+00
PRASEODYMIUM		.0 E+00	.0 E+00
CERIUM		.0 E+00	.305E-03
LANTHANUM		.0 E+00	.678E-03
BARIUM		.229E-01	.373E-02
CESIUM		.0 E+00	< .118E-03
IODINE		.0 E+00	.236E-03
TELLURIUM		.0 E+00	< .136E-03
ANTIMONY		.0 E+00	< .240E-03
TIN		.0 E+00	.101E-06
CADMIUM		.0 E+00	.118E-03
SILVER		.0 E+00	.170E-02
MOLYBDENUM		.0 E+00	.749E-03
NIOBIUM		.0 E+00	.678E-03
ZIRCONIUM		.0 E+00	.213E-02
YTTRIUM		.0 E+00	.680E-04
STRONTIUM		.115E-01	.576E-03
RUBIDIUM		.0 E+00	< .626E-03
BROMINE		.0 E+00	.518E-02<X<.586E-02
SELENIUM		.0 E+00	.403E-06<X<.678E-03
ARSENIC		.0 E+00	< .240E-03
GERMANIUM		.0 E+00	.101E-06
GALLIUM		.229E-02	.403E-06
ZINC		.688E-01	.238E-01
COPPER		.138E+00	.132E-01
NICKEL		.183E+00	.733E-02
COBALT	<	.458E-02	.199E-04
IRON		.596E+00	.483E-01
MANGANESE		.115E-01	.284E-02
CHROMIUM		.229E-01	.693E-02
VANADIUM		.183E-01	.421E-03
TITANIUM		.229E+00	.136E-02
SCANDIUM		.0 E+00	< .339E-04
CALCIUM		.367E+00	.964E-01
POTASSIUM		.151E+01	.277E+00
CHLORINE		.115E+00	.165E-01
SULFUR		.756E+00	> .404E+00
PHOSPHORUS		.115E+00	.826E-02
SILICON		.367E+00	.194E+00

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MASS/HEAT INPUT

TESCO
LOW NOX
NG/J

ELEMENT	FUEL OIL	HEATER OUTLET
ALUMINUM	.298E+00	.200E-01
MAGNESIUM	.275E+00	.236E-02
SODIUM	.136E+00	> .173E+00
FLUORINE	.917E-02	.118E-03
BORON	.229E-01	.0 E+00
BERYLLIUM	.0 E+00	< .101E-06
LITHIUM	.458E-01	.151E-05

TCSCO
LCW NOX

CONCENTRATION
MCG/DSCM

ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
URANIUM	.121E-02	.0 E+00	.0 E+00	N .0 E+00	.121E-02
THORIUM	.121E-02	.0 E+00	.0 E+00	.0 E+00	.121E-02
LEAD	.213E-01	.0 E+00	.121E+01	N .0 E+00	.124E+01
MERCURY	< .402E-01	< .202E+00	< .965E-02	< .676E-01	< .319E+00
GOLD	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
PLATINUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
HAFNIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
CERIUM	.0 E+00	.0 E+00	.121E+01	N .0 E+00	.121E+01
LANTHANUM	.0 E+00	.0 E+00	.270E+01	N .0 E+00	.270E+01
BARIUM	.643E-01	.938E+01	.540E+01	N .0 E+00	.148E+02
CESIUM	.0 E+00	< .469E+00	.0 E+00	N .0 E+00	< .469E+00
IODINE	.0 E+00	.938E+00	.0 E+00	N .0 E+00	.938E+00
TELLURIUM	< .402E-03	.0 E+00	< .540E+00	N .0 E+00	< .540E+00
ANTIMONY	N .0 E+00	N .0 E+00	N .0 E+00	< .957E+00	< .957E+00
TIN	.402E-03	.0 E+00	.0 E+00	N .0 E+00	.402E-03
CADMIUM	.402E-03	.469E+00	.0 E+00	N .0 E+00	.470E+00
SILVER	.398E-01	.0 E+00	.675E+01	N .0 E+00	.679E+01
MOLYBDENUM	.354E-01	.282E+01	.135E+00	N .0 E+00	.299E+01
NIOBIUM	.0 E+00	.0 E+00	.270E+01	N .0 E+00	.270E+01
ZIRCONIUM	.0 E+00	.469E+01	.378E+01	N .0 E+00	.847E+01
YTTRIUM	.803E-03	.0 E+00	.270E+00	N .0 E+00	.271E+00
STRONTIUM	.0 E+00	.0 E+00	.229E+01	N .0 E+00	.229E+01
RUBIDIUM	.0 E+00	< .469E+00	< .202E+01	N .0 E+00	< .249E+01
BROMINE	.402E-02	.206E+02	< .270E+01	N .0 E+00	.206E+02<X<.233E+02
SELENIUM	.161E-02	.0 E+00	< .270E+01	N .0 E+00	.161E-02<X<.270E+01
ARSENIC	N .0 E+00	N .0 E+00	N .0 E+00	< .957E+00	< .957E+00
GERMANIUM	.402E-03	.0 E+00	.0 E+00	N .0 E+00	.402E-03
GALLIUM	.161E-02	.0 E+00	.0 E+00	N .0 E+00	.161E-02
ZINC	.177E+00	.0 E+00	.945E+02	N .0 E+00	.947E+02
COPPER	.321E-01	.282E+02	.243E+02	N .0 E+00	.525E+02
NICKEL	.358E+01	.0 E+00	.256E+02	N .0 E+00	.292E+02
COBALT	.791E-01	.0 E+00	.0 E+00	N .0 E+00	.791E-01
IRON	.112E+01	.136E+03	.553E+02	N .0 E+00	.193E+03
MANGANESE	.321E-01	.469E+00	.108E+02	N .0 E+00	.113E+02
CHROMIUM	.159E+00	.221E+02	.540E+01	N .0 E+00	.276E+02
VANADIUM	.802E+00	.469E+00	.405E+00	N .0 E+00	.168E+01
TITANIUM	.0 E+00	.0 E+00	.540E+01	N .0 E+00	.540E+01
SCANDIUM	.0 E+00	.0 E+00	< .135E+00	N .0 E+00	< .135E+00
CALCIUM	U .0 E+00	.371E+03	.135E+02	N .0 E+00	.384E+03
POTASSIUM	U .0 E+00	.110E+04	U .0 E+00	N .0 E+00	.110E+04
CHLORINE	U .0 E+00	.657E+02	.0 E+00	N .0 E+00	.657E+02
SULFUR	> .562E+00	.328E+03	> .128E+04	N .0 E+00	> .161E+04
PHOSPHORUS	.522E-01	.328E+02	.0 E+00	N .0 E+00	.329E+02
SILICON	U .0 E+00	.774E+03	.0 E+00	N .0 E+00	.774E+03

TCSCQ
LCW NOX

CONCENTRATION MCG/DSCM

ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
ALUMINUM	U .0 E+00	.798E+02	.0 E+00	N .0 E+00	.798E+02
MAGNESIUM	U .0 E+00	.938E+01	.0 E+00	N .0 E+00	.938E+01
SODIUM	U .0 E+00	> .690E+03	U .0 E+00	N .0 E+00	> .690E+03
FLUORINE	.0 E+00	.469E+00	.0 E+00	N .0 E+00	.469E+00
BORON	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
BERYLLIUM	< .402E-03	.0 E+00	.0 E+00	.0 E+00	< .402E-03
LITHIUM	.603E-02	.0 E+00	.0 E+00	N .0 E+00	.603E-02

MASS/TIME	TGSCO LOW NOX MCG/SEC				
ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
URANIUM	.396E-02	.0 E+00	.0 E+00	N .0 E+00	.396E-02
THORIUM	.396E-02	.0 E+00	.0 E+00	.0 E+00	.396E-02
LEAD	.700E-01	.0 E+00	.400E+01	N .0 E+00	.407E+01
MERCURY	< .132E+00	< .663E+00	< .311E-01	< .222E+00	< .105E+01
GOLD	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
PLATINUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
HAFNIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
CERIUM	.0 E+00	.0 E+00	.400E+01	N .0 E+00	.400E+01
LANTHANUM	.0 E+00	.0 E+00	.888E+01	N .0 E+00	.888E+01
BARIUM	.211E+00	.309E+02	.178E+02	N .0 E+00	.488E+02
CESIUM	.0 E+00	< .154E+01	.0 E+00	N .0 E+00	< .154E+01
IODINE	.0 E+00	.309E+01	.0 E+00	N .0 E+00	.309E+01
TELLURIUM	< .132E-02	.0 E+00	< .178E+01	N .0 E+00	< .178E+01
ANTIMONY	N .0 E+00	N .0 E+00	N .0 E+00	< .315E+01	< .315E+01
TIN	.132E-02	.0 E+00	.0 E+00	N .0 E+00	.132E-02
CADMIUM	.132E-02	.154E+01	.0 E+00	N .0 E+00	.154E+01
SILVER	.131E+00	.0 E+00	.222E+02	N .0 E+00	.223E+02
MOLYBDENUM	.116E+00	.926E+01	.444E+00	N .0 E+00	.982E+01
NIOBIUM	.0 E+00	.0 E+00	.888E+01	N .0 E+00	.888E+01
ZIRCONIUM	.0 E+00	.154E+02	.124E+02	N .0 E+00	.279E+02
YTTRIUM	.264E-02	.0 E+00	.888E+00	N .0 E+00	.890E+00
STRONTIUM	.0 E+00	.0 E+00	.755E+01	N .0 E+00	.755E+01
RUBIDIUM	.0 E+00	< .154E+01	< .666E+01	N .0 E+00	< .820E+01
BROMINE	.132E-01	.679E+02	< .888E+01	N .0 E+00	.679E+02<X<.768E+02
SELENIUM	.528E-02	.0 E+00	< .888E+01	N .0 E+00	.528E-02<X<.888E+01
ARSENIC	N .0 E+00	N .0 E+00	N .0 E+00	< .315E+01	< .315E+01
GERMANIUM	.132E-02	.0 E+00	.0 E+00	N .0 E+00	.132E-02
GALLIUM	.528E-02	.0 E+00	.0 E+00	N .0 E+00	.528E-02
ZINC	.581E+00	.0 E+00	.311E+03	N .0 E+00	.311E+03
COPPER	.106E+00	.926E+02	.799E+02	N .0 E+00	.173E+03
NICKEL	.118E+02	.0 E+00	.843E+02	N .0 E+00	.961E+02
COBALT	.260E+00	.0 E+00	.0 E+00	N .0 E+00	.260E+00
IRON	.370E+01	.447E+03	.182E+03	N .0 E+00	.633E+03
MANGANESE	.106E+00	.154E+01	.355E+02	N .0 E+00	.372E+02
CHROMIUM	.523E+00	.725E+02	.178E+02	N .0 E+00	.908E+02
VANADIUM	.264E+01	.154E+01	.133E+01	N .0 E+00	.551E+01
TITANIUM	.0 E+00	.0 E+00	.178E+02	N .0 E+00	.178E+02
SCANDIUM	.0 E+00	.0 E+00	< .444E+00	N .0 E+00	< .444E+00
CALCIUM	U .0 E+00	.122E+04	.444E+02	N .0 E+00	.126E+04
POTASSIUM	U .0 E+00	.363E+04	U .0 E+00	N .0 E+00	.363E+04
CHLORINE	U .0 E+00	.216E+03	.0 E+00	N .0 E+00	.216E+03
SULFUR	> .185E+01	.108E+04	> .422E+04	N .0 E+00	> .530E+04
PHOSPHORUS	.172E+00	.108E+03	.0 E+00	N .0 E+00	.108E+03
SILICON	U .0 E+00	.255E+04	.0 E+00	N .0 E+00	.255E+04

TOSCO
LOW NOX

MASS/TIME MCG/SEC

ELEMENT	FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS	HEATER OUTLET
ALUMINUM	U .0 E+00	.262E+03	.0 E+00	N .0 E+00	.262E+03
MAGNESIUM	U .0 E+00	.309E+02	.0 E+00	N .0 E+00	.309E+02
SODIUM	U .0 E+00	> .227E+04	U .0 E+00	N .0 E+00	> .227E+04
FLUORINE	.0 E+00	.154E+01	.0 E+00	N .0 E+00	.154E+01
BORON	.0 E+00	.0 E+00	.0 E+00	N .0 E+00	.0 E+00
BERYLLIUM	< .132E-02	.0 E+00	.0 E+00	.0 E+00	< .132E-02
LITHIUM	.198E-01	.0 E+00	.0 E+00	N .0 E+00	.198E-01

TGSCO
LOW NOX

MASS/TIME MCG/SEC ELEMENT	FUEL OIL	HEATER OUTLET
URANIUM	< .874E+02	.396E-02
THORIUM	< .983E+02	.396E-02
LEAD	.983E+02	.407E+01
MERCURY	N .0 E+00	< .105E+01
GOLD	.0 E+00	.0 E+00
PLATINUM	.120E+04	.0 E+00
HAFNIUM	.0 E+00	.0 E+00
PRASEODYMIUM	.0 E+00	.0 E+00
CERIUM	.0 E+00	.400E+01
LANTHANUM	.0 E+00	.888E+01
BARIUM	.109E+03	.488E+02
CESIUM	.0 E+00	< .154E+01
IODINE	.0 E+00	.309E+01
TELLURIUM	.0 E+00	< .178E+01
ANTIMONY	.0 E+00	< .315E+01
TIN	.0 E+00	.132E-02
CADMIUM	.0 E+00	.154E+01
SILVER	.0 E+00	.223E+02
MOLYBDENUM	.0 E+00	.982E+01
NIOBIUM	.0 E+00	.888E+01
ZIRCONIUM	.0 E+00	.279E+02
YTTRIUM	.0 E+00	.890E+00
STRONTIUM	.546E+02	.755E+01
RUBIDIUM	.0 E+00	< .820E+01
BROMINE	.0 E+00	.679E+02<X<.768E+02
SELENIUM	.0 E+00	.528E-02<X<.888E+01
ARSENIC	.0 E+00	< .315E+01
GERMANIUM	.0 E+00	.132E-02
GALLIUM	.109E+02	.528E-02
ZINC	.328E+03	.311E+03
COPPER	.655E+03	.173E+03
NICKEL	.874E+03	.961E+02
COBALT	< .218E+02	.260E+00
IRON	.284E+04	.633E+03
MANGANESE	.546E+02	.372E+02
CHROMIUM	.109E+03	.908E+02
VANADIUM	.874E+02	.551E+01
TITANIUM	.109E+04	.178E+02
SCANDIUM	.0 E+00	< .444E+00
CALCIUM	.175E+04	.126E+04
POTASSIUM	.721E+04	.363E+04
CHLORINE	.546E+03	.216E+03
SULFUR	.360E+04	> .530E+04
PHOSPHORUS	.546E+03	.108E+03
SILICON	.175E+04	.255E+04

TGSCO
LOW NOX

MASS/TIME MCG/SEC ELEMENT	FUEL OIL	HEATER OUTLET
ALUMINUM	.142E+04	.262E+03
MAGNESIUM	.131E+04	.309E+02
SODIUM	.655E+03	> .227E+04
FLUORINE	.437E+02	.154E+01
BORON	.109E+03	.0 E+00
BERYLLIUM	.0 E+00	< .132E-02
LITHIUM	.218E+03	.198E-01

TCSCO
LOW NOX
MCG/SEC
HEATER MASS BALANCE

IN: FUEL OIL OUT : HEATER EXHAUST GAS ELEMENT	TOTAL IN	TOTAL OUT	MASS BALANCE(OUT/IN)
URANIUM	X<.874E+02	.396E-02	.454E-04 <X
THORIUM	X<.983E+02	.396E-02	.403E-04 <X
LEAD	.983E+02	.407E+01	.414E-01
MERCURY		X<.105E+01	*
GOLD			*
PLATINUM	.120E+04		.0 E+00
HAFNIUM			*
PRASEODYMIUM			*
CERIUM		.400E+01	*
LANTHANUM		.888E+01	*
BARIUM	.109E+03	.488E+02	.447E+00
CESIUM		X<.154E+01	*
IODINE		.309E+01	*
TELLURIUM		X<.178E+01	*
ANTIMONY		X<.315E+01	*
TIN		.132E-02	*
CADMIUM		.154E+01	*
SILVER		.223E+02	*
MOLYBDENUM		.982E+01	*
NIOBIUM		.888E+01	*
ZIRCONIUM		.279E+02	*
YTTRIUM		.890E+00	*
STRONTIUM	.546E+02	.755E+01	.138E+00
RUBIDIUM		X<.820E+01	*
BROMINE		.679E+02<X<.768E+02	*
SELENIUM		.528E-02<X<.888E+01	*
ARSENIC		X<.315E+01	*
GERMANIUM		.132E-02	*
GALLIUM	.109E+02	.528E-02	.484E-03
ZINC	.328E+03	.311E+03	.950E+00
COPPER	.655E+03	.173E+03	.263E+00
NICKEL	.874E+03	.961E+02	.110E+00
COBALT	X<.218E+02	.260E+00	.119E-01 <X
IRON	.284E+04	.633E+03	.223E+00
MANGANESE	.546E+02	.372E+02	.681E+00
CHROMIUM	.109E+03	.908E+02	.832E+00
VANADIUM	.874E+02	.551E+01	.631E-01
TITANIUM	.109E+04	.178E+02	.163E-01
SCANDIUM		X<.444E+00	*
CALCIUM	.175E+04	.126E+04	.723E+00
POTASSIUM	.721E+04	.363E+04	.503E+00
CHLORINE	.546E+03	.216E+03	.396E+00
SULFUR	.360E+04	.530E+04 <X	.147E+01 <X
PHOSPHORUS	.546E+03	.108E+03	.198E+00
SILICON	.175E+04	.255E+04	.146E+01

TOSCO
LOW NOX
MGS/SEC
HEATER MASS BALANCE

IN: FUEL OIL OUT : HEATER EXHAUST GAS

ELEMENT	TOTAL IN	TOTAL OUT	MASS BALANCE(OUT/IN)
ALUMINUM	.142E+04	.262E+03	.185E+00
MAGNESIUM	.131E+04	.309E+02	.235E-01
SODIUM	.655E+03	.227E+04 <X	.346E+01 <X
FLUORINE	.437E+02	.154E+01	.353E-01
BORON	.109E+03		.0 E+00
BERYLLIUM		X<.132E-02	
LITHIUM	.218E+03	.198E-01	.907E-04